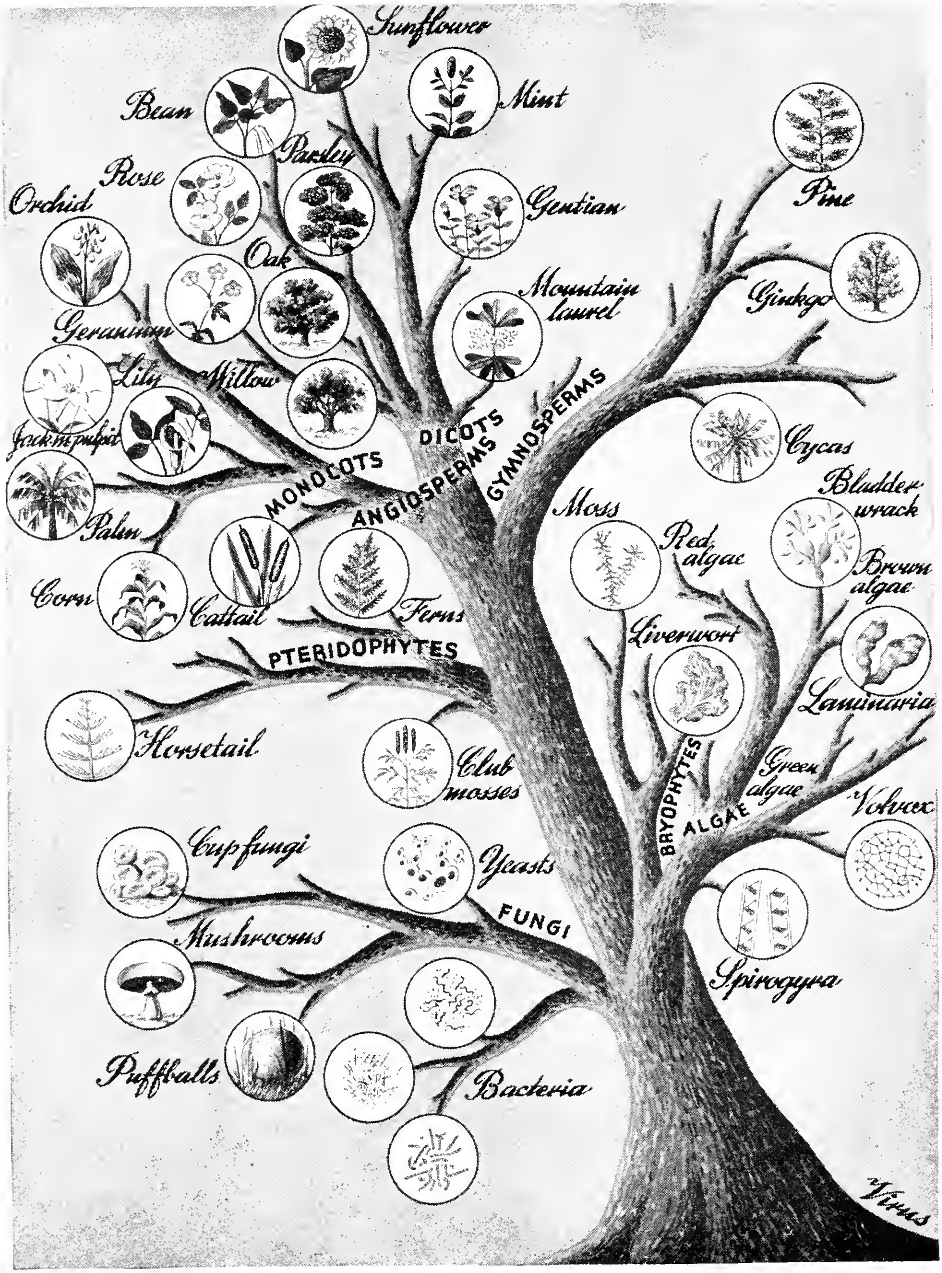
GRUENBERG

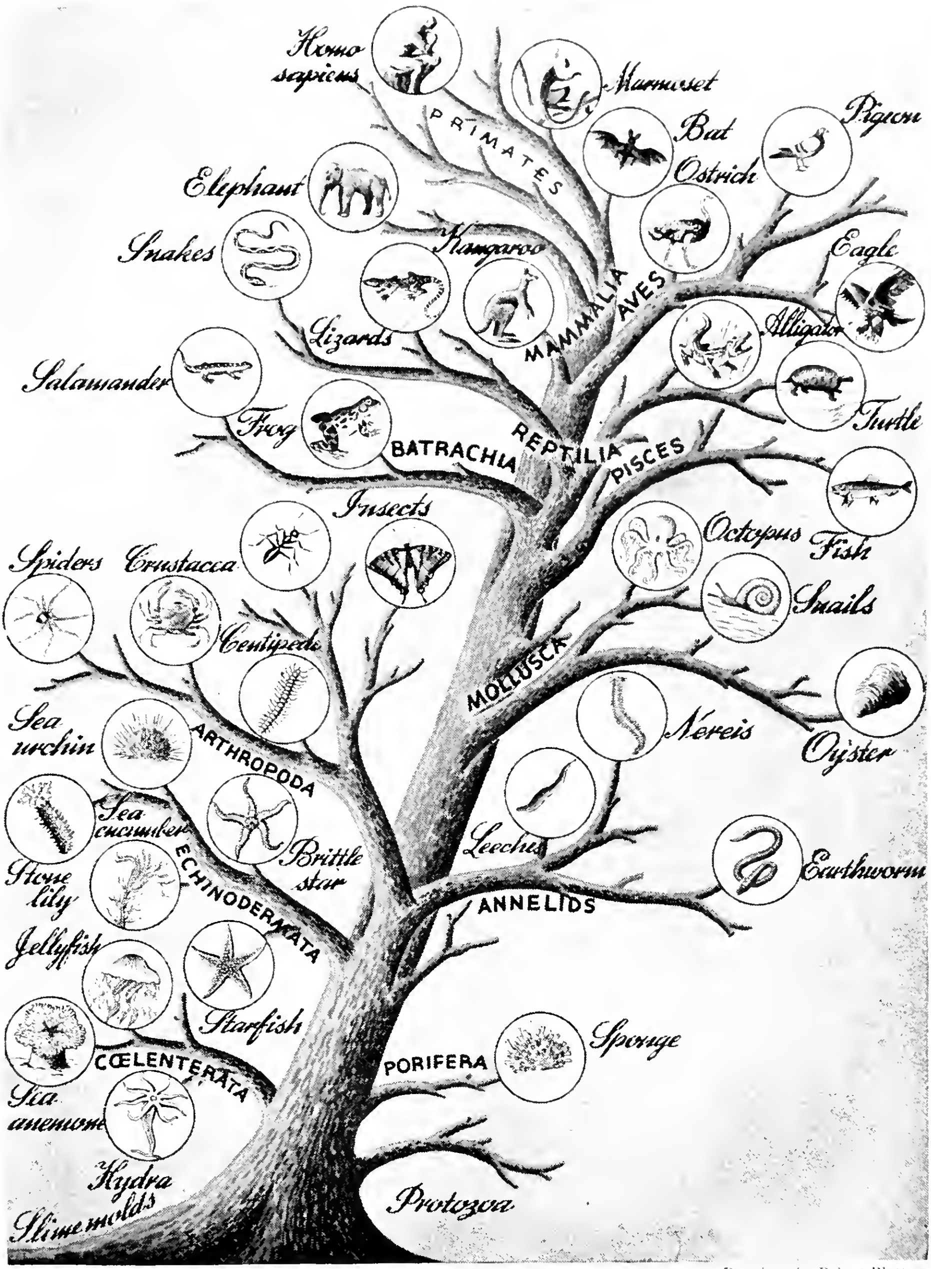
BIOLOGY AND MAN

BINGHAM



THE FAMILY TREE OF PLANT LIFE

When we try to sort living things (or any other things, for that matter), we find our arrangements branching off the main line and branching off again and again, like the twigs of a tree. Some living forms cannot be classed definitely as plants or definitely as animals



Drawings by Robert Blattner

THE FAMILY TREE OF ANIMAL LIFE

The farther a type is from the base of the trunk, the more complex and the more distinctive it is, as a rule. If we suppose that each living form descended from another plant or animal, the arrangement suggests that in the course of time species departed from ancestral types

BIOLOGY AND MAN

By

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PREFACE

Our secondary schools today are common schools in the sense that elementary schools were *common* fifty years ago. That is, they enroll somewhat over two thirds of the boys and girls of the age they are designed to serve. In the past our high schools were responsible for special services to boys and girls who were in line for careers in the professions or for leadership in their communities. Today our high schools must furnish guidance, instruction and training of value to everybody. We have tried in this book to introduce a unified science of living things, which we regard as a valuable part of our common heritage.

Like the traditional three R's of our common schools, this introduction opens the way for all, expecting that each will continue as far as he wishes or needs to along particular lines. Some will wish to go further with botany or entomology, for example, or with gardening or breeding, whether as a hobby or as a profession. Some will wish to become nurses or technicians, physicians or administrators, and so will follow their "biology" in different directions. And some will find that this book will serve as a solid and ample foundation for college work.

These young men and women honestly want to understand the essential facts of personal and social life and the practical implications of these facts for themselves. These students are already on the verge of being the adult workers and voters and policy-makers of their time. They will have to decide scores of issues involving human beings as organisms—organisms that want food and shelter, that want to be well and to prolong their lives, that have to live together without destroying one another. These young men and women want to know more about the human species than they can possibly get out of the specialized subjects that ignore the organic nature of man, and more than they can possibly get out of a "biology" that ignores the distinctively human characteristics of this particular species—its intellect, its imagination, its inventiveness, its emotions and sentiments, and the very sociality that makes it possible for us to have any science at all.

We have accordingly tried to depict life in terms sufficiently broad to include man himself and sufficiently concrete to be within the grasp of the common mind. This has meant developing the material from points of view that are generally meaningful, the familiar functions, activities and relationships of living things: eating and breathing, growing and maturing, origins and developments and death, health and sickness, the helps and hindrances to life that come from the inanimate world and from other living things—and from the doings and intrusions of man.

Each unit and each chapter of this book starts with a number of questions that represent, in our experience, the common curiosities and wonderings of young people. These questions focus the interest and attention of the reader and give direction to the discussion. But there is no pretense that these questions are about to be answered; for while they are genuine and relevant enough, they cannot always be answered in the form they take. Many imply assumptions that are at least of doubtful validity; others involve ambiguous terms. Even a question consisting of but a few familiar words may be quite unanswerable. Why is sugar sweet? Or, Why is blood red? The easiest answers to give and to "understand" and to remember are of course the oldest answers—the kind that primitive man could think up and that the race has indeed remembered to this very moment. Since we frequently are not satisfied with such answers, for we believe them to be often not only evasions of the questions but in most cases effective obstacles to further thinking, we have assumed that it is a large part of our task to clarify the very questions for which answers are sought. At the ends of the chapters are questions (sometimes the "same" questions) which we assume now have new meanings, explore new understandings; and, again, there are questions that can be answered only by interpreting meanings.

Accepting the scientific way of constructing knowledge out of thought and experience, we suggest at the ends of the chapters numerous "explorations and projects", through which students may obtain practical experience in organizing material to guide and check their thinking. (These activities are referred to by number in footnotes at the points in the chapters where they are likely to be most helpful.)

Another characteristic of the scientific method is the analysis of materials and problems into smaller and smaller bits in search of the ultimate atoms. This leads to a rapid expansion of our knowledge; but it often results in forms of thinking that disregard major problems of daily living. We hope to counteract such atomism by making it clear that life is essentially an integrative process, one of bringing various elements together into dynamic wholes. We consider it of special importance today to further a common understanding of the role of co-ordination wherever there is "division of labor", in social life as well as in organisms. This need seems to us quite urgent in a time when the great conflicts of the world arise from the efforts of the several self-conscious groups, associations, classes, nations and other fragments of mankind to control for private ends the social and cultural values to which all have contributed and which arise in any case only from social and cultural interactions.

We have taken special pains with the illustrations and are particularly grateful to the artists, photographers and others, whose co-operation is acknowledged throughout. The drawings are by Bernard Friedman, Hag-

strom Company, Marcel Janinet, Herbert Paus, Hugh Spencer, and Karsten Stapelfeldt. Although many of the illustrations are more or less self-contained in that each conveys a complete idea, they, with their accompanying legends, are intended to be integral supports for the text. Many are, of course, convenient devices for conveying ideas of structure or of form; but most of them involve ideas of process, of relationship, of historical development, or of logical development. In some cases they raise questions that cannot be answered on a purely "factual" basis. All these graphic pieces are intended to facilitate the work of the student, but for the most part they cannot be lightly skimmed over like items in a picture book: they call for close attention and reflection.

We have been helped in our work by the many colleagues in the business of teaching and by the many students through whom we think we have come to understand the problems of the learner and his world. We wish to acknowledge especially the helpful suggestions and criticisms and detailed information and other material received from Dr. Louis I. Dublin, Chief Statistician, Metropolitan Life Insurance Company; Dr. A. H. Ebeling, Lederle Laboratories; T. Swann Harding, United States Department of Agriculture; Dr. Charles R. Knight, American Museum of Natural History; Professor Oliver Laud, Antioch College; Algernon Lee, New York; Dr. Lloyd A. Rider and Dr. Milton Hecht, Abraham Lincoln High School, Brooklyn; and Mrs. Emily Eveleth Snyder, High School, Little Falls, New York.

B. C. G.
N. E. B.

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BIOLOGY AND MAN

INTRODUCTION

You and Biology

You have to learn biology, whether you like it or not. Everybody does. And why so? Because the curriculum requires it? Or because some college entrance board says so? Not for these reasons. It is because we are the kind of people that we are. Indeed, all of us have already learned a great deal of biology—very largely without meaning to. It just cannot be helped.

Life Is Everywhere As far back in time as human beings first roamed the earth, they were surrounded by many different kinds of plants and animals. All around were many kinds of birds, many kinds of fur-bearing animals, both large and small, many kinds of creepy and crawly things, bugs and worms and spiders, and fleas too. In the waters were many kinds of fish and crabs and clams, as well as frogs and newts, which shifted between land and water. There were trees and shrubs and herbs, with flowers and thorns and berries, and some with thick, fleshy roots.

What We Need to Know Through all the ages it must have been necessary for human beings to *know* a great deal about many of these plants and animals, and for two very good reasons.

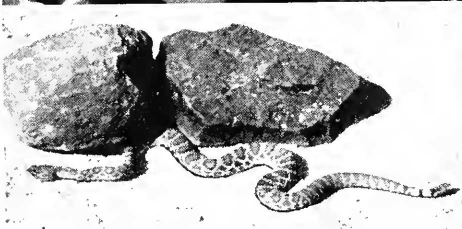
First, it was necessary to know which of these natural objects could be used for food, or for clothing, shelter, tools, and weapons. Is *that* good to eat? Is that kind of wood good for a bow or for a club?

Second, it was necessary to know which of these different kinds of things were injurious or dangerous. Is *that* snake poisonous? or that berry? Is that animal one to run after, or one to run away from?

It is important to know how different kinds of birds and fishes *behave*, or we should have no luck killing or catching them. It is necessary to know something of the *habits* of wild beasts if we are to act in a manner that suits our needs.

If you want to raise beans, you have to know something of the conditions suitable to the growth of beans. If you want to get rid of poison ivy or rats, you have to know what conditions destroy these forms of life. If you care about your own well-being, you must know some things about the workings of your own body: you must know what dangers to avoid, what conditions favor health, what to do in an emergency.

Human beings have, in fact, always known a great deal about plant life and about animal life. Such knowledge is, as you can see, extremely practical—that is, it bears directly upon what people *do*. Two plants or two



Rattler

Copperhead

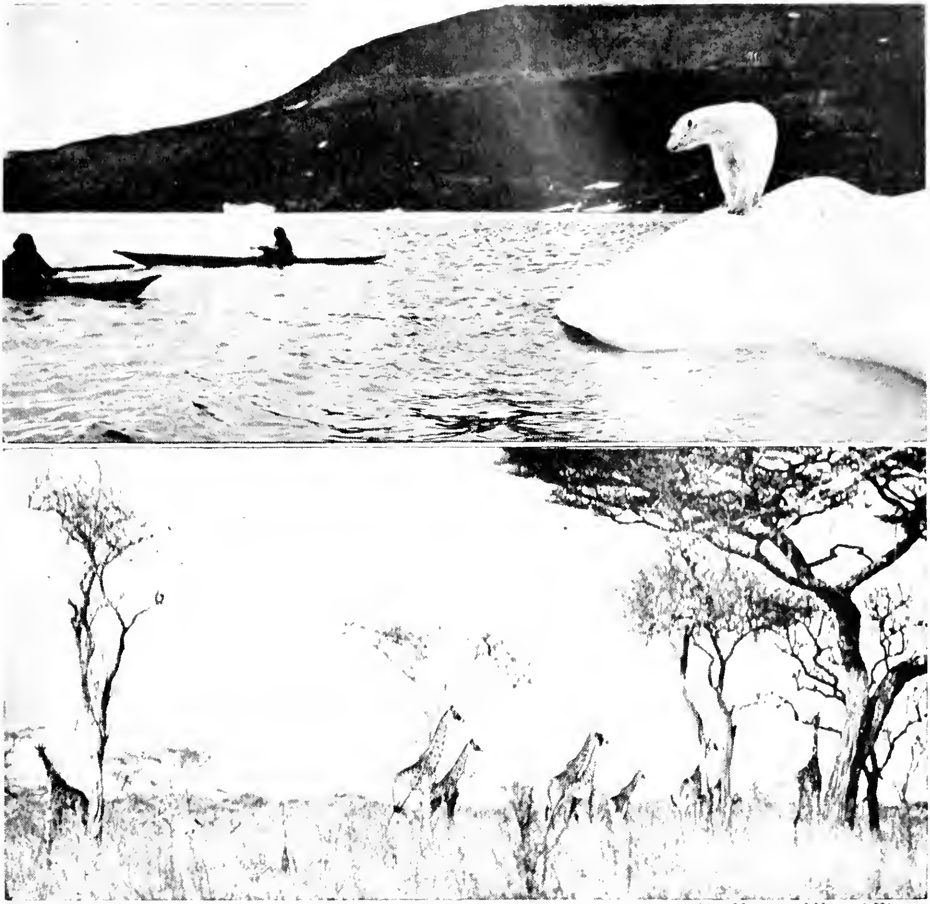
American Museum of Natural History

KNOWLEDGE AND ACTION

To some people all snakes look alike; but it is not safe to treat them all alike. With a little biological knowledge (about snakes) one learns that it is safe to handle a black or garden snake and to treat the rattler or the copperhead in a different way

birds may look enough alike to confuse the ordinary observer; and one may be fit to eat while the other is decidedly not. It is important to *distinguish.*

Biology The vast knowledge about plants and animals which people must have had from earliest times was divided in small bits among the many scattered tribes. Until modern times there was not even a name for this knowledge or study about living things. The word *biology* is from the Greek *bios* ("life") and *logos* ("word" or "knowledge"), and means life-knowledge, or life-science. It was first used in this sense by a German botanist (a student of plants) named Treviranus, who in 1802 published a book with the title *Biology, or a Philosophy of Living Nature.*



American Museum of Natural History

BIOLOGY STARTS AT HOME

People living in the uplands of Africa know some biology of the giraffe, but little about the lobster or the walrus. Eskimos can manage animals of the arctic, but know nothing of coons or squirrels. But everybody learns some biology

If the subject is so important, why did it take so long to reach a common name for it? A general science of living things became possible only after human beings began to move away from their villages and hamlets, and to see strange people, strange plants and animals. People had first to discover that the world is much larger than their own country, and that it contains many "wonders" that are perfectly familiar and commonplace to other people.

The Greeks appear to have been the first people who tried in an orderly way to bring together facts about all kinds of animals and plants from all parts of the world. Collecting samples from everywhere must have been

very difficult. Luckily, the emperor Alexander ordered his governors and generals to send natural objects from all regions, to please his old teacher Aristotle.

As people traveled more widely and saw more and more kinds of living things, they naturally changed their ideas about life. For one who moves about must broaden his outlook upon the world. He comes to see his fellows and the other inhabitants of the earth in a different way from one who lives always in the same neck of the woods or along the same stretch of shore.

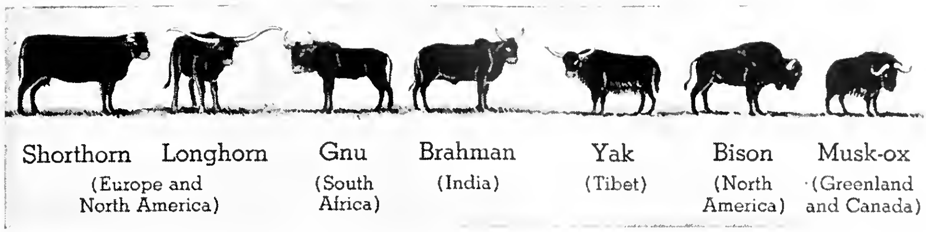
As time goes on, we move about and see larger regions of the world and more of its inhabitants. Wherever strangers meet, knowledge increases: we learn from each other. We thus lengthen our lists of known plants and animals and find new uses for various kinds. The Spanish missionaries brought Peruvian bark to Europe; and for over three centuries that was the only remedy we had for malaria. People formerly threw to the dogs portions of food animals which we now know to be worth more to us than the meat itself. A few very old men and women remember when the tomato was considered a poisonous fruit. The weeds and vermin of one region are valued and cultivated in another.

Men migrating to new regions often found new pests attacking their crops or their cattle. And they often met new diseases too. As population grows, we have to make farms yield more. Growing cities create problems of water supply and ventilation, sanitation and the transporting of food, which is always in danger of spoiling. New chemicals and smokes and dusts in new industries bring new problems of protecting the health of workers.

Today, when planes encircle the globe in a few days, or survey inaccessible mountain valleys, or bring together on short notice representatives of widely scattered peoples, biology means more than ever. Plants and animals of any region come to be important to people far away. Human life everywhere may profit from whatever people anywhere can get out of biology, whether it is a substitute for quinin or an antitoxin, a new sulfa drug or a new idea about managing things. And flying itself is possible for more people only as special biological problems are solved.

Modern biology, or life science, is thus one of the outcomes of the great social, economic, and political changes of the past three or four centuries. And in turn biology is bringing about still further changes—many of them no doubt improvements in our ways of living.

Kinds of Biology We can ask many different questions about any given subject. Among the first questions that each of us probably asked after we learned to speak are those that have to do with *class*, or kind. What kind of tree is that? What kind of stone is that? And the usual



THE FAMILIAR AND THE STRANGE

Cowlike animals found in various parts of the world are all alike in some ways. But the strangers differ from the cow and also from one another

answer is a *name*: that is a sycamore tree; that is a ruby. Sorting and naming are, of course, very important to us, especially while we are growing up and constantly coming across strange new objects. But the task is endless, for there are a million or more distinct kinds of animals and probably as many kinds of plants. There are numerous varieties of apples or wheat, hundreds of species of beetles and clams. It is impossible for anybody to "know all the kinds of living things". How many different kinds of oak trees can you distinguish, or dogs, or butterflies, or roses? Classifying and naming plants and animals occupy large numbers of men and women the world over. This branch of biology is called *taxonomy*, from a Greek word meaning "arrangement" or "order".

Other common questions about living things have to do with the use we can make of them, or with the harm they may do. But to answer such questions about the *economics* of plants and animals, we must be able to distinguish the various kinds. The logwood tree, a relative of the locust tree living in semitropical regions, was formerly the chief source of black dye. But shiploads of "logwood" came to market with none of the essential pigment-producing materials: the "real" logwood and the not-quite-the-same logwood were not easily distinguishable.

We commonly recognize familiar species of plants and animals by their general forms, sometimes relying upon surface patterns or coloring. But that raises special problems. For example, is a worm to be considered a small snake, or a snake a large worm? Is the whale a kind of fish? Is moss a kind of grass?

The more closely we examine and compare plants and animals, the more satisfactorily can we arrange them or sort them. But then we raise new problems. For example, we notice that the arms of a man "correspond" in some way to the forelegs of a horse or a squirrel, and also to the wings of a bird; yet the wings of a bird and those of a butterfly do not correspond in the same way, although they do the same kind of work.

Again, we notice that the whole collection of living things in any one place is constantly changing. Has each kind always existed as we see it now? What of the kinds that formerly lived here? How did the individuals originate? Even if we begin with the practical questions of getting what we need and avoiding injury, many other questions are bound to arise. What conditions favor living or interfere with it? How do different kinds of living things influence one another? Each of these questions may start us off on a new study or special "science of life", of which there are many.

The answers we get to such questions make us *act* differently in connection with various plants and animals, including other people. But what we do changes the conditions around us—and raises new problems.

So we have to learn about living beings, including ourselves, whether we like biology or not. And everybody is doing it. For biology is that branch of science which has to do especially with life processes. This knowledge helps us to preserve and improve our own lives.

UNIT ONE

What Is Life?

1 How many different kinds of animals are there?
2 How many different kinds of plants are there?
3 What does it mean to say that the tiger belongs to the cat family?
4 In what ways are different kinds of animals "related", or different kinds of plants?
5 How can we recognize each kind of animal or each kind of plant?
6 Can one kind of living thing be changed into another kind?
7 In what ways is man like animals?
8 Is man the most important being in the world?

The proper study of mankind, said Alexander Pope, is man. Centuries before the time of Pope a wise Greek recommended "Know thyself." But one difficulty in studying ourselves is the fact that we are too close to ourselves to see clearly. And we have our prejudices too. Besides, it does seem rather conceited. For how important are we, or how important is mankind?

When Columbus started on his journey toward the setting sun, practically everybody in Europe thought that the earth was the center of the universe: it was put there to be the abode of man. Fifty years after Columbus returned, Galileo and other scientists stirred up a great deal of bitter feeling by suggesting that the earth moves around the sun, not the sun around the earth. This idea caused much excitement because it pushed man with his little earth away from the center of the stage. It seemed to belittle man. And people—mostly poor, frightened, helpless—could not endure that.

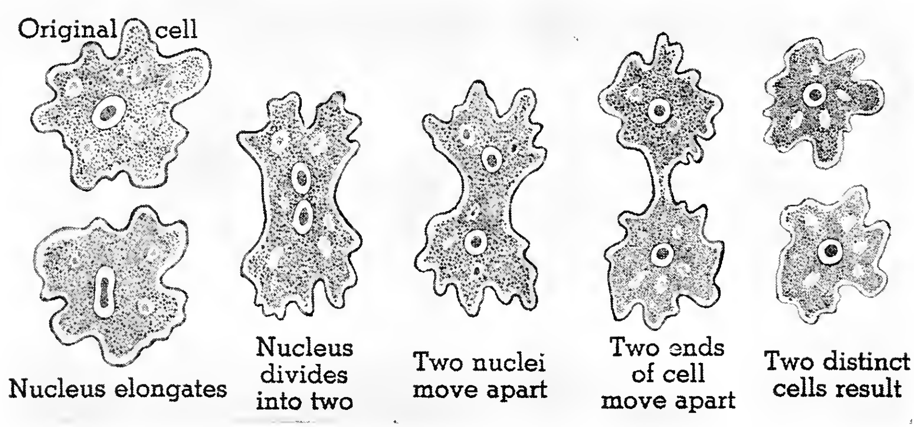
Yet what *is* more important than man? Larger animals, or taller trees, or tougher fighters? Is a rare flower or insect or diamond more important? How can we get outside ourselves in order to see in true perspective? We do actually compare ourselves with one another in order to decide upon relative merits and capacities. We compare ourselves with other living things too. We may assume without apology that man stands rather high among all living beings, if only because he alone appears capable of *asking such questions*!

At any rate, there is only one excuse for all our effort, all our wondering and investigating and puzzling. And that is to enable human beings to live better, to get along better, to get more satisfaction, to enjoy life more. For us, at least, man is the most important thing in the world, and life the most important happening.

To investigate "life" we must begin with ourselves, for we have to start

from wherever we happen to be—which is with ourselves. Indeed, we cannot do otherwise. We "understand" other people as we recognize in their actions our own purposes and motives and interests. When people act in ways very different from our ways, they may amuse us or annoy us, but they also puzzle us. And we try to "understand" other living things, and even nonliving things, by assuming that they have purposes and concerns like ours.

We enlarge our knowledge by moving away from our starting-point. We compare more and more kinds of living things with ourselves, but also with one another. We compare living things with those that are not alive. We try to find out what the living and the nonliving have to do with each other, how they are related. We try to find out what "life" is by studying its various forms and its ways of acting—and what it means to man, who is still at the center of our universe. By enlarging our knowledge we come slowly to useful understandings, which help us to get along better.



THE LIFE OF A SIMPLE ANIMAL

The ameba has no definite shape, but moves about, pushing its jellylike mass now in one direction, now in another. After an ameba reaches its full growth, the nucleus, or kernel, lengthens out and gradually divides into two parts. The rest of the animal's body also lengthens, and the two ends seem to move slowly away from each other until there are two distinct individuals. Each of these is as complete as the other, and both are the same as the original mother cell except for size

CHAPTER 1 · WHAT DISTINGUISHES LIVING THINGS?

1 Are there animals that do not move?
2 Can plants feel?
3 Can insects hear?
4 Are plants alive in the same way as animals are?
5 What is there the same about plants and animals?
6 Are animals alive in the same way as we are?
7 Can plants protect themselves?
8 What becomes different in a plant or an animal when it dies?
9 Can part of a living animal be dead, like a dead branch on a tree?
10 Are there parts of animals that are of no use?

We distinguish various kinds of natural objects by their colors, shapes, sizes, and arrangement of parts. But being *alive* is not like being round or soft or purple. It means *doing* something. Living is acting in a certain way.

When we speak of a "live spring" or of a "live volcano", we mean that there is action. But we do not confuse a spring or a volcano with living things. A cloud moves across the sky, and it constantly changes its shape; but it is not alive. Action is a *necessary* part of our idea of life; but action is not *sufficient* to distinguish the living from the nonliving.

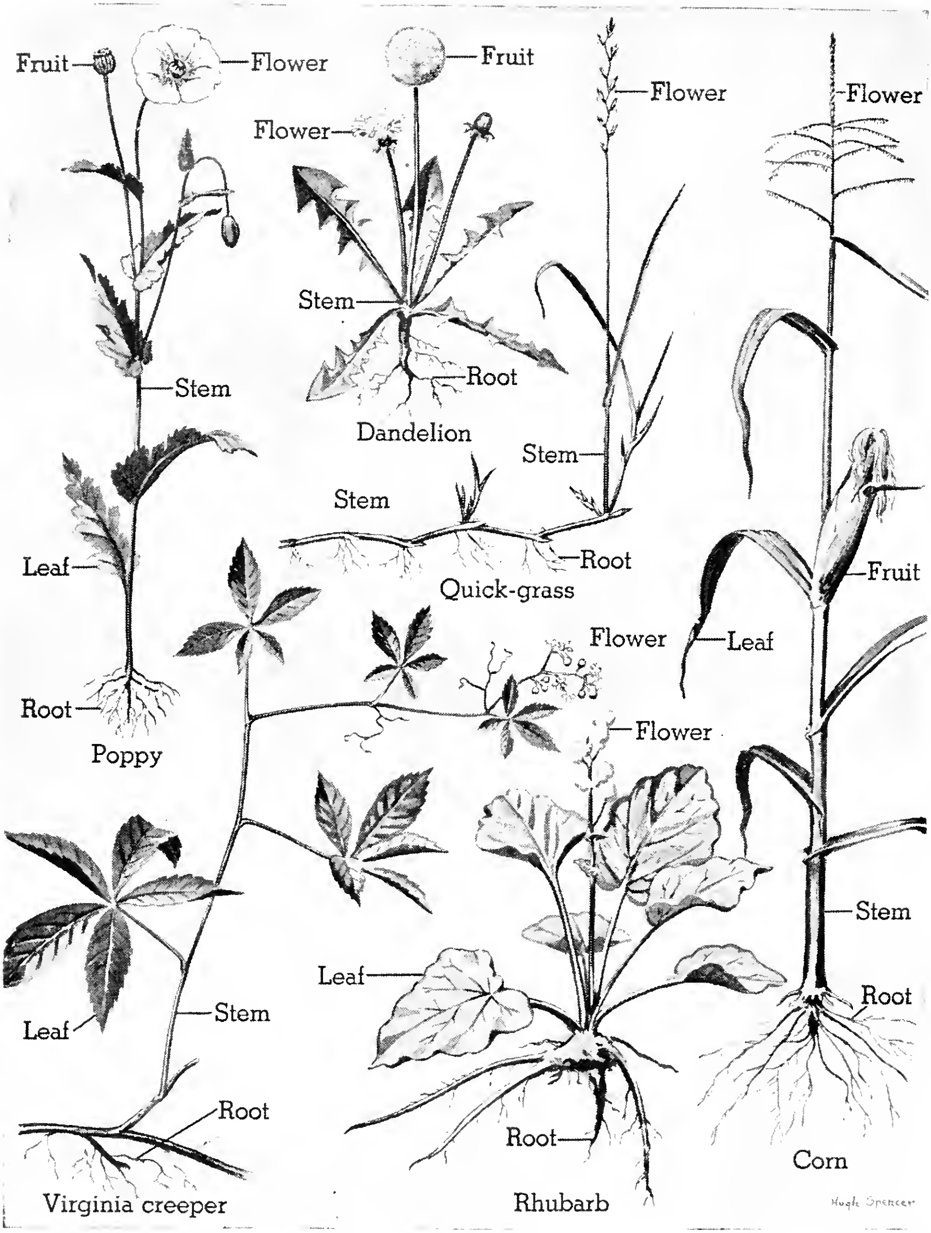
How do living things differ from other objects? Is it their structure? or their chemical composition? or the particular things they do? or the way they originate? Are plants alive in the same way as we are? What is there about living things that makes them alive, that keeps them alive?

How Are Plants and Animals Alike?

The Parts of Plants[1] If we examine a geranium plant, or any other small plant that is easily handled, we find that the part below ground (the *root*) differs in several ways from the part above ground (the *shoot*). They differ in color and in texture. The smallest branches or subdivisions of the root are, as a rule, more delicate than those of the shoot. In most kinds of plants the shoot consists of distinct *stem* and *leaves*, which differ from each other in shape, color, and texture.

At certain seasons of the year the stem bears other structures besides leaves, namely *flowers*. Most kinds of flowers last but a short time and are succeeded by *fruits*, inside of which there are usually *seeds*. And these parts, the seeds, as we already know, are the beginnings of new plants.

[1]See No. 1, p. 27.



A WHOLE PLANT

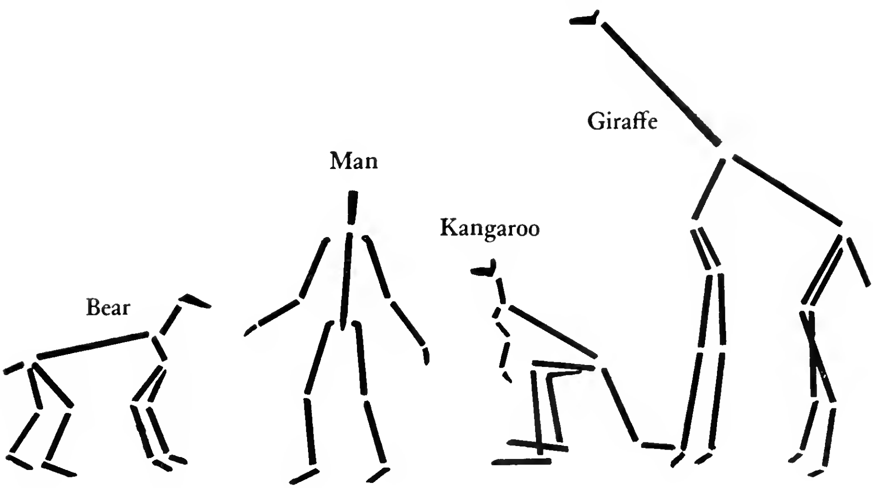
Most familiar plants consist of an underground portion, the root, and of a portion above ground, the shoot. The shoot is made up of stem and leaves. And on some special stems, or stalks, there are special clusters of leaves which together make up a flower. In some plants the root seems exceptionally large; or the stem may be underground; or roots may appear aboveground

BILATERAL, OR TWO-SIDED, SYMMETRY[1]

The three "faces" are of the same person. The middle is a normal full-face photograph. The first is made up of the right half of the face and a "mirror image" of the same. The third consists of the left half with its "mirror image"

We might say of such plants, (1) their bodies consist of distinct parts, and (2) the parts undergo orderly changes in the course of the year.

The Human Body Since we are most familiar with our own bodies, we naturally use the body as a standard for judging other living things, or



BODY PLAN OF MAMMALS

In all these animals there is a main axis, with the head at the front end. There are two pairs of limbs—the front ones attached at the "shoulders" and the hind ones attached at the "hips"

[1]From *Expression of Personality* by Werner Wolff. By permission of Harper & Brothers.

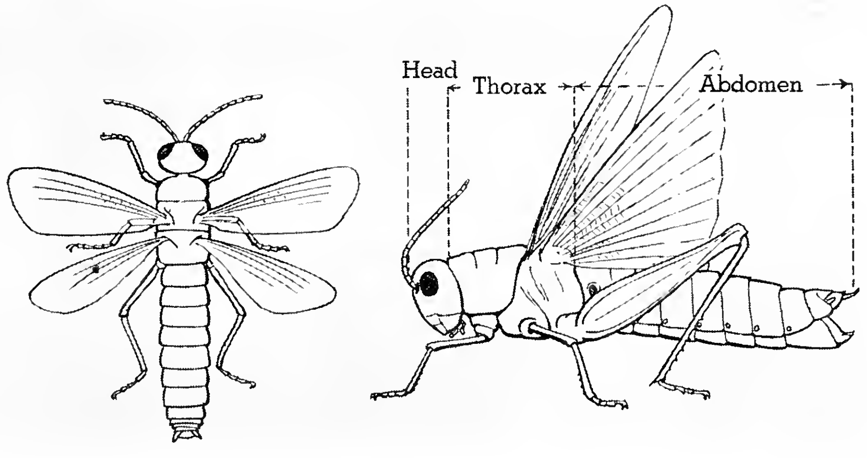
as the basis of "reference". Cats, dogs, horses, cows, and other familiar *mammals* (animals that suckle their young) do resemble the human body in many ways. They all have a two-sided symmetry, the right and left sides being almost mirror-images of one another (see illustration, p. 13). They all have the same body "plan" (see illustration, p. 13).

On the head are three pairs of special structures—the eyes, the ears, and the nostrils—which seem to relate the animal to the outside world. The mouth or food opening is in the middle line, below the nostrils. At the posterior or hind end of the trunk are special openings that are related to removing wastes from the body, and to reproduction.

The skin of mammals usually has a more or less complete hairy cover. Although the limbs of common mammals are jointed or hinged, the body covering shows no distinct breaks over the joints. The forward part of the trunk, the *thorax* or chest, has a firm wall made up of curved bones, the ribs. The hind part of the trunk, the abdomen, has no such enclosing framework (see illustration, p. 48).

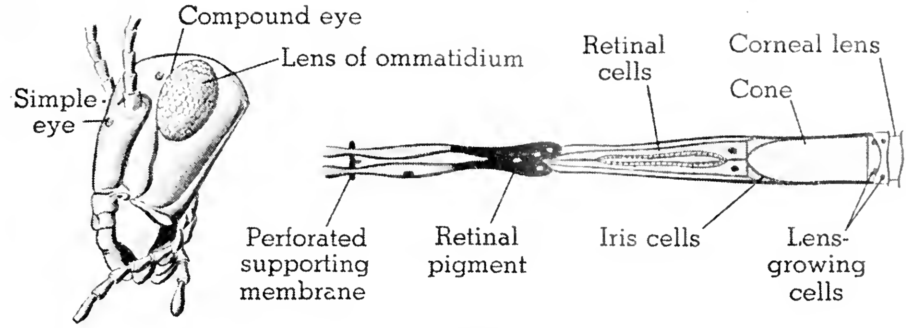
An Insect In the grasshopper, a representative insect, the general plan of structure is that of a main body with distinct regions and several kinds of outgrowths or attachments (see illustration below).

The head bears two feelers, or *antennae* (singular, *antenna*), projecting forward. The eyes occupy a large part of the surface of the head. Since each of these consists of numerous complete eyes, it is called a *compound* eye (see illustration, p. 15). In addition, there are three tiny simple eyes



THE BODY PLAN OF AN INSECT

In the grasshopper, as in other insects, the bilateral body is made up of a rather distinct head at the front end; the main "trunk", or abdomen; and, between these, the thorax, which bears both the legs and the wings. The grasshopper has a rather large eardrum near the front end of the abdomen



INSECT EYES

The head of a locust showing the compound eye with its many facets, each representing the exposed surface of an ommatidium, or single eye, and an ommatidium seen in section cut lengthwise. In the arthropods, or animals with jointed legs, there are compound eyes, as well as simple ones

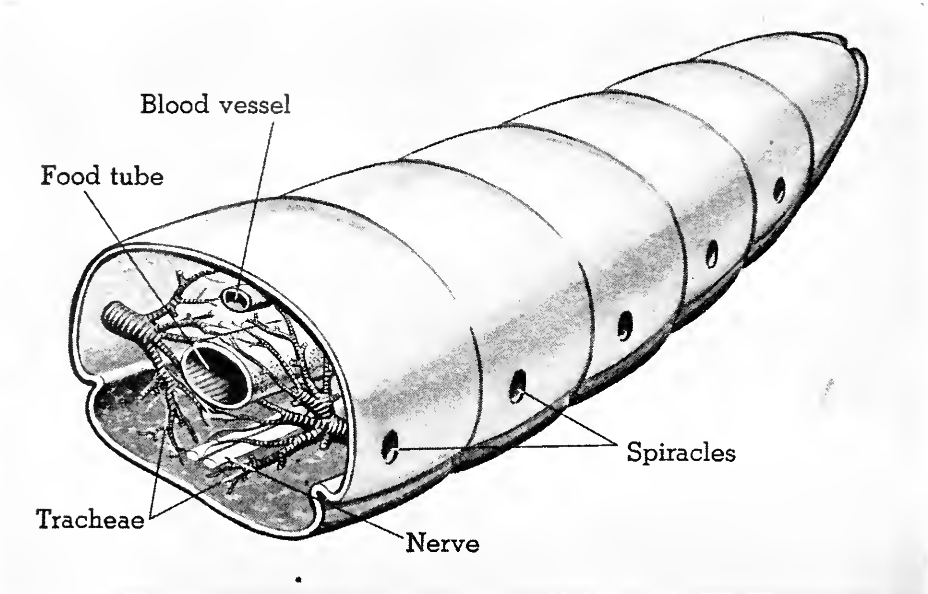
on the front of the head. The mouth, at the lower end of the head, consists of several distinct parts.

The thorax, which is covered by the wings when the animal is at rest, is made up of three more or less distinct *segments*, or rings. Each segment carries one pair of jointed legs. Two of the segments carry one pair of wings each, and the anterior (forward) wings cover the posterior (hind) ones when at rest.

The abdomen, like the thorax, is distinctly segmented. Indeed, the name of this class of animals, Insects, refers to the fact that the body is "cut in", or segmented, like the body of a caterpillar. This is easily observed in the abdomen of dragonflies, bees, moths and beetles (see illustrations opposite). The foremost segment has on each side a small *tympanum*, or drum, which is actually an eardrum (see illustration opposite). The hindmost segment bears special structures that have to do with the removal of refuse, other structures with reproduction. In the female these terminal parts together constitute the egg-laying organ, or ovipositor.

The bodies of insects and of mammals, like the bodies of plants, consist of many distinct parts or organs. And if we take the time to watch any animals over a long period, we see that they too, like plants, undergo regular changes in form and in behavior.

Comparing The moment we begin to compare carefully, we discover that structures can correspond in many ways and yet not be *the same*, even if we call them by the same name. Thus parts may be "alike" in relative position—as the "tail" of a cat and the "tail" of a dragonfly,



BREATHING TUBES IN INSECTS

Each spiracle in the side of the body opens into a trachea, which branches repeatedly and brings air to all the tissues

which is really the abdomen (see illustration, p. 18), or as the "thorax" of an insect and a human thorax, which differ in both their structures and their workings.

Sometimes a name is carried over on account of similarities in the *functions* or workings of parts. Thus, the insect type, represented by a grasshopper, and the mammal type, represented by man, both have eyes, or *seeing* organs; legs, or *locomotor* organs; and jaws, or *food-chewing* organs. Yet the insect's eyes, legs, and jaws differ from the corresponding organs of the mammal in many details of form and structure, and in the way they develop from the earliest stages. Again, leaves have been called the "lungs" of plants because in both leaves and lungs an exchange of gases takes place between the inside and the outside. Yet the two do not resemble each other at all in appearance, in structure, or in actual workings.

Such comparisons bring out many differences among living things, as well as many resemblances. Through them we come to certain general facts that are the same in plants and animals.

Activities of Animals[1] Every familiar animal moves from place to place. It also moves its parts, as in striking or biting. To us such movements at once suggest other activities. Mouth movements suggest eating. Eye movements suggest searching and watching. The movements of an insect's antennae suggest groping or "feeling", as we feel with our fingers.

From our past experience we know that food is related to growing. And while neither a person nor any other animal enlarges under our eyes, we know that each must have grown, for neither was born full size. And that suggests another thing that animals do: they reproduce. There is also about each animal something that makes it move or *change* its movements when certain outside conditions act upon its feelers, or eyes, or ears, for example.

Some of the animals we know eat one kind of food, some another. Some grow rapidly, some slowly. But all take in food and grow. So, too, animals differ as to how sensitive they are, as to what kinds of conditions influence them, and as to how rapidly or how vigorously they move. But all are sensitive to changes, and all do move. And all animals originate from other animals of the same kind.

Activities of Plants What now of plants? We know that plants grow. When we want new plants for any purpose, we usually look to getting them from seeds, which in turn come from other plants. That is, plants reproduce themselves. But do they also move? Is a plant sensitive to what goes on around it?

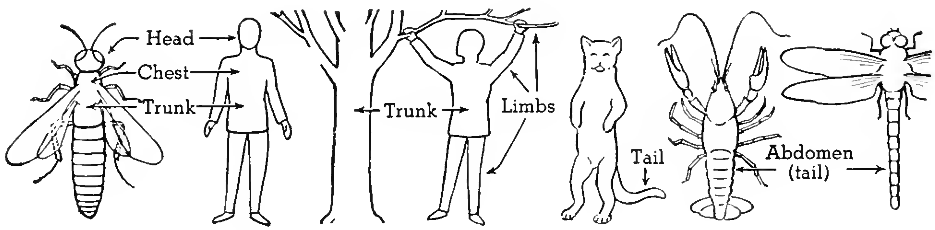
Most of us have not noticed whether plants do really move or whether they respond to changes in their surroundings. Certainly plants do not reach out and grasp food, as do the kitten and the baby, for example. Nor does the plant eat with a mouth. Still the very fact of growing, which depends upon taking in food, implies some movement. The plant does take materials into itself from its surroundings, by way of the roots and by way of the leaves. And it does move, or transport, these materials from one part to another.

Most of the movements in a plant are slow and minute, so that we should need a microscope to observe them directly. But we can easily observe a rapid movement of the leaves of a disturbed sensitive-plant. And we can observe slower, yet very distinct, turnings of many common plants toward the light (see illustration, p. 257). These movements show us that plants *are* sensitive to what is going on around them.

[1]See No. 2, p. 27.

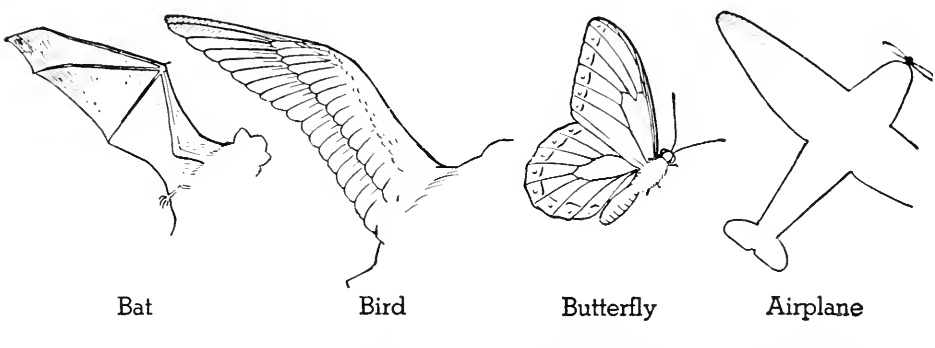
Thus we find that plants and animals have in common certain processes or characteristics. They take food and they grow. They are sensitive. They move. They reproduce themselves. There are, to be sure, many differences also, but we are considering now their common characteristics.

Organisms Each of the distinct parts in a plant or animal is something more than a structural unit, like one of the bricks which make up a wall. Each special structure carries on a particular kind of work, it behaves in a particular way in relation to the other parts or in relation to the whole plant or animal. It is for this reason that each of the special parts is called an *organ*, or instrument. That is, each performs some special service or "function" in relation to the whole body. Most organs or parts do something toward keeping the body alive. Any plant or animal that you know is made up of organs. Although living things do not all have exactly the same organs, the term *organism* is a useful one to mean any living being.



DIFFERENT WAYS IN WHICH ORGANS CORRESPOND

We often use the common names of the familiar parts of our own bodies for corresponding parts of other objects, living and nonliving. The trunk and limbs of a tree do correspond to the trunk and limbs of a human body, but only superficially



The wings of a bat, of a bird, and of a butterfly "correspond" to the wings of an airplane; but in structure, development, and workings they are quite different

TWO KINDS OF GROWTH

Both plants and sand dunes enlarge by taking substances from the outside world. The dune grows as the winds bring it more sand, and as some of the grains stay put. The plant, however, grows by absorbing many different kinds of stuff from the air and from the soil, by transforming this material into new combinations, some of which are finally plant stuff, and by laying down particles of plant stuff in all its parts

How Do Organisms Differ from Nonliving Things?

Growth All living things grow. Yet the crystals of many substances also grow, some of them very rapidly, even as we watch them. Most of us have seen icicles grow. If by growing we mean simply becoming larger, then snowdrifts and icicles grow just as truly as beets or babies. What, then, is the real difference between the two kinds of growing?

An icicle becomes larger as new layers of ice-stuff (water) are added. The growth of a crystal proceeds in the same way. A baby, however, does not grow in this manner. The icicle grows by the piling on of ice material on the surface, or by *accretion.* The baby, like other living things, grows not by adding to the surface but by adding materials in all parts. Moreover, it transforms into its own substance stuff from the outside that is different: the organism *assimilates,* or makes stuff like itself.

Irritability[1] We perceive lights and colors, sounds, odors, and tastes. From the movements of familiar animals we infer that they are also influenced by what happens around them. A dog does something when he is struck. Your eye does something when there is a sudden flash of light. Even a geranium plant changes its behavior when placed in a sunny window. The effects of these happenings are different from those caused by dropping a cup, for example, or by striking a stone. This *irritability,* or sensitiveness, of living things is in some ways the most remarkable fact about them.

[1]See No. 3, p. 27.

Yet sensitiveness is not altogether confined to living things. The chemical compounds of the photographic film are in some ways even more sensitive than plants and animals. Some compounds are so sensitive that they will produce a violent reaction when they are dropped. It may be more disastrous to push a hot poker into a stick of dynamite than to poke a vicious dog. Unlike a living organism, however, the sensitive dynamite is destroyed by its reaction.

Fitness If an animal is attacked, it usually acts in a way that will probably save it from further injury. Thus, when a dog's tail is pulled he will try to run away, or he will bark or snap at the "thing-holding-tail". On seeing its kind of food, an animal will usually take steps to get it. Such responses tend, on the whole, to *preserve* life. This characteristic of plants and animals is sometimes called *adaptiveness*, or the capacity to fit, more or less completely, the surrounding conditions. Indeed, how could organisms continue to live, generation after generation, if they acted exactly the same under all circumstances?

Origin We know nothing about the first appearance of life upon the earth. So far as our observation has gone, each plant and animal begins its existence in or on the body of some other plant or animal. In general, organisms reproduce themselves, but nonliving bodies do not.

Being Alive We may conclude that a living organism, a plant or an animal, is distinguished by these characteristics: It originates from another similar organism. It takes in materials from the outside and *assimilates* this food into its own substance. It transforms the assimilated material, getting from it the energy by which it *moves* and carries on other processes. It is *sensitive* to the conditions and changes in its surroundings. It responds to changes in ways that are *adaptive*—that is, more or less suited to preserving it, or *keeping it alive*. It may reproduce others like itself.

The adaptiveness of a plant or animal is never perfect. Most living things suffer injury or privation, and are at last starved or destroyed. Living is a risky business. But even under most favorable conditions, the regular changes which normally take place in a living plant or animal at last come to an end. If not previously "killed", the organism eventually stops living. It *dies*. Dying is part of life. Nonliving objects can of course be destroyed: but they do not "die".

What Is there about Plants and Animals That Keeps Them Alive?

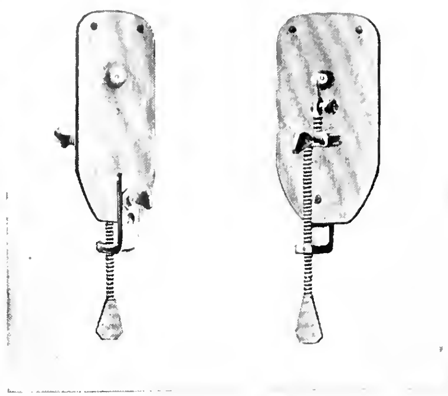
Cells[1] Plants and animals differ greatly in their forms and in structure and activities; yet they are alike in growing, moving, being irritable,

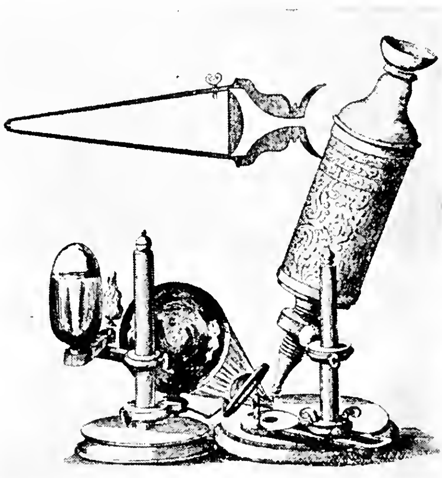
[1]See No. 4, p. 27.

Anton van Leeuwenhoek (1632–1723) was a Dutch businessman with the hobby of making microscopes and looking at things nobody had ever seen before. He discovered tiny animals in pond-water

One of Leeuwenhoek's microscopes. Through the nearly spherical lens in a copper plate tiny objects could be seen greatly magnified

The Bettmann Archive





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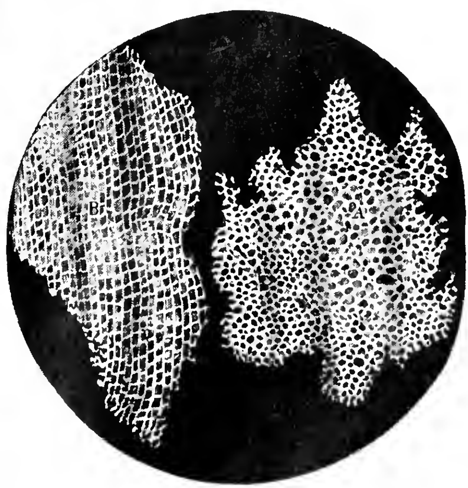
An English contemporary of Leeuwenhoek's, Robert Hooke (1635–1703), had the same hobby. As a scientist he made more systematic studies of bits of plants and animals

In a thin slice of oak bark or cork, Hooke saw little compartments to which he gave the name cells or chambers, since they suggested the cells of a beehive or the rooms of a house. The Italian Malpighi also saw such "cells" in other plant fragments



THE MICROSCOPE AND CELLS

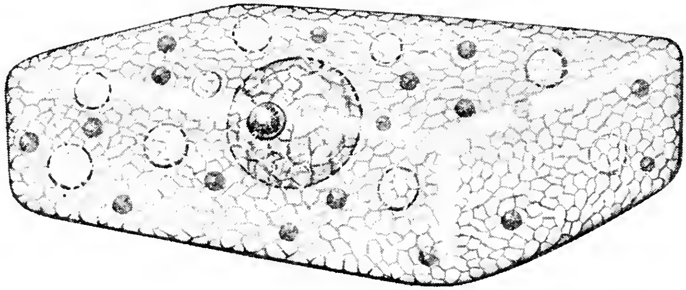


DIAGRAM OF A CELL

Under better microscopes the living stuff looks like a very fine foam full of tiny bubbles, or like a very fine network in which tiny particles are enmeshed. It is the protoplasm that is the living content of the cell, and that actually builds up the cell

and being adaptive. Where is the underlying sameness? It was impossible to answer this until the microscope had been improved to a certain point.

In the seventeenth century it was already possible to find hundreds of living things that are too small for the human eye to see unaided. A Dutch merchant, Anton van Leeuwenhoek (1632–1723), and an English contemporary, Robert Hooke (1635–1703), made their own microscopes and peered at all kinds of very small objects. In a thin slice of cork Hooke saw little compartments to which he gave the name *cells*, or chambers, since they reminded him of the cells of a beehive—or a monastery (see illustration, p. 21).

Subsequently hundreds of students saw that all the plants and animals that they examined consist of "cell", although these are of many sizes and shapes. In 1839 a German botanist, Matthias Schleiden (1804–1881), and his friend Theodor Schwann (1810–1832), a zoologist, developed the idea that the "cell" is the "unit of structure" in all living things (see illustration, p. 21). They were not clear as to just what goes on in the cell. And they gave their attention mostly to the walls or membranes of the cells. But using the cell idea led to further important discoveries.

Protoplasm About a hundred years ago various investigators in France, Italy, Germany, Bohemia, and no doubt elsewhere, were searching in cells for the secret of life. They began to observe a curious slimy or jelly-like substance in both plant material and animal material—something like white-of-egg in appearance. By 1840 the Bohemian scholar Johannes Evangelista Purkinje (1787–1869) suggested the name *protoplasm* (from *protos*, first, and *plasm*, forming-material). Other investigators hit upon

the idea that this protoplasm is essentially the same in all plants and animals. It has, in fact, been called "the living substance", although we know that it is a very complex mixture of many different substances (see illustration, p. 22).

We continue to speak of the cell as "the unit" of living things, even

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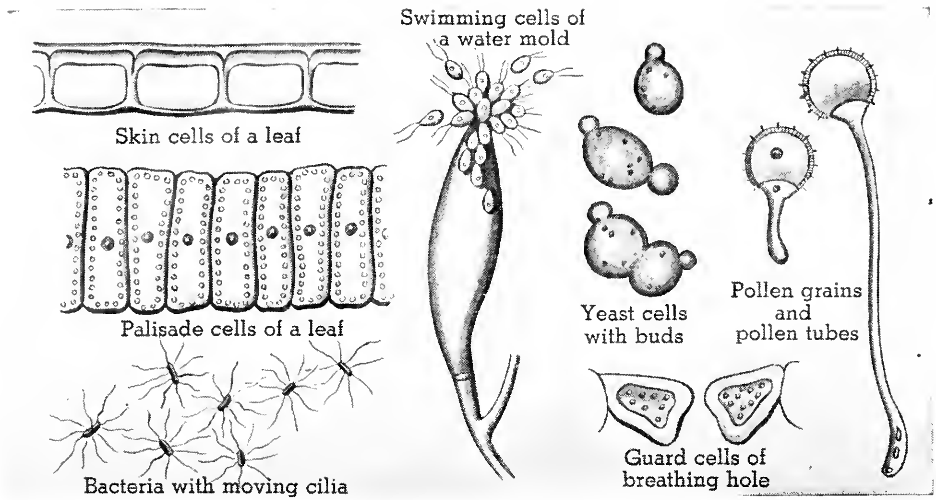
AN EXCEPTIONALLY LARGE AMEBA, Chaos chaos

The protoplasm is constantly stirring around, constantly changing its shape, moving sluggishly about. The slimy mass wraps itself around food particles, and it crawls away from particles within that are no longer usable. Without distinct regions or organs, the ameba does all it takes to keep alive



TYPES OF PLANT CELLS

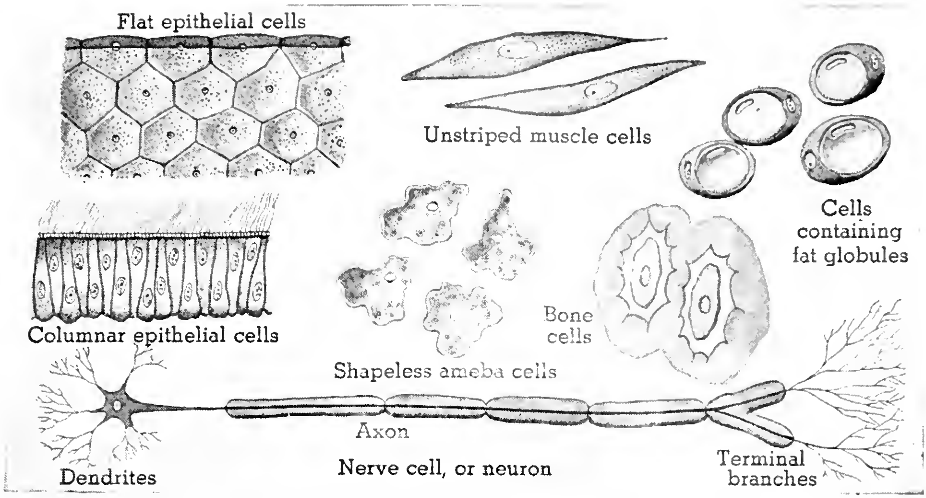
though in many of the simplest plants and animals the body is *not* divided into distinct chambers or cells. We speak of the individuals in these forms as consisting of single cells.

One of the simplest animals is the ameba, which lives in stagnant pools and looks like an irregular lump of jelly enclosing tiny granules and bubbles. The animal responds to physical and chemical disturbances by contracting the protoplasm, or by drawing in its pseudopodia, or "false feet".

Variety of Cells When we look at an ordinary plant or animal, we do not see the protoplasm, nor even the cells, but masses of *walls* of cells. In the larger plants and animals the outer layers of cells are usually dead—that is, they are walls without living protoplasm, just the kinds of cells that Hooke saw in cork. The microscope enables us to see that some cells have thicker walls or enclosing membranes than others, some hardly any (see illustrations, pp. 24–25). We can see various kinds of solid bodies floating in the protoplasm. There are also bubbles of clearer liquid. In some living cells it is possible to see the protoplasm streaming about (see illustration, p. 26).

Nucleus Near the center of each living cell, or at one side, we can usually find a portion that seems more dense than the rest. This is called the *nucleus*, which means "kernel". Since protoplasm is usually transparent, it is difficult to distinguish its structure, even with the microscope. Now we know that various kinds of dyes stain some materials more readily than others. We can therefore use them to help distinguish the nucleus as well as other structures in bits of plant and animal tissue (see illustration, p. 10).

Multiplication of Cells Most of the plants and animals that you have seen contain indefinite but very great numbers of cells. Some living things,



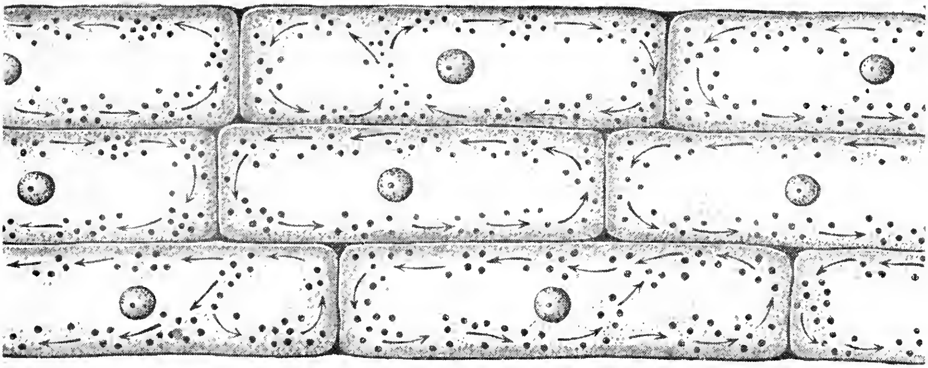
TYPES OF ANIMAL CELLS

however, consist of very few cells or, like the ameba, of a single cell. Bacteria, of which everybody hears a great deal, are one-celled plants. So are many algae, for example the "green-slime", which lives on the shady side of trees or on damp shingles. But every plant or animal, whether it consists of a single protoplasm unit or of many millions of cells, starts out as a single cell. Among the one-celled organisms, a new individual originates by a comparatively simple division of a parent cell—one cell becomes two! The nucleus divides into two equal parts, and then the rest of the protoplasm divides. Thus two distinct cells result (see illustration, p. 10).

In many-celled animals the body grows as cells increase in size. When a particular cell reaches its full size, it may divide into two. The nucleus splits first and then the rest of the protoplasm. A new individual usually arises from special cells which become separated from the parent body (see Chapter 19).

Protoplasm Is Fundamental In the one-celled ameba, as we have seen, *the single bit of protoplasm carries on all the life activities.* It grows, it moves, it reproduces, and so on. Yet in the larger plants and animals, those having many kinds of cells and millions of each kind, *the protoplasm of each cell carries on the same fundamental activities.* However different a bone cell may be from a brain cell, or a tree cell from a dog cell, the protoplasm in all cases is irritable, it can grow, it can move, and at some stage of its life it can reproduce itself.

The many different kinds of plants and animals, with their peculiar forms and organs and many kinds of activities, are a constant source of wonder. Yet they all apparently arise from protoplasm, which is always the



PROTOPLASM MOVES

In many types of cells that have been studied, we can see portions of the fluid streaming or circulating about, as suggested by the arrows

same in some respects, but always capable of changing as circumstances change. Fundamentally the same in all organisms, it is in every particular case distinct and peculiar. That is characteristic of protoplasm, as it is characteristic of life.

At any rate, scientists are pretty well agreed that it is this protoplasm of a plant or a kitten that grows. It is protoplasm in the body of the Venus's fly-trap or of a snake that moves when the organism springs upon its victim. It is the protoplasm of the geranium or of the worm that is sensitive to light.

In Brief

Plants and animals take in food and grow by assimilation; nonliving objects grow only by accretion.

Living plants and animals move through processes going on inside the organisms, while inorganic objects are pushed around by outside forces.

Living things are irritable, or sensitive to changes in their surroundings.

The responses of living things to disturbances are generally adaptive; that is, they tend to help living things to keep on living.

Living things originate from others of the same kind, and may produce offspring like themselves.

Living things consist of special parts, or organs, that carry on distinct services or functions.

Protoplasm, the living stuff of organisms, is a very complex mixture of many different substances. It is distributed in more or less distinct and specialized units called cells.

In all kinds of organisms the protoplasm of each cell grows, reproduces, moves, and is irritable. In the larger plants and animals individual cells carry on specialized activities in addition to the fundamental ones.

EXPLORATIONS AND PROJECTS

1 To survey the "whole plant", compare in several different kinds of plants the main structural parts; look for and record suggestions as to the different ways in which each part contributes to the life of the plant.

2 Study grasshoppers. Note and list the many things that this living organism does but that nonliving objects do not do. Note carefully also *how* it does everything it does. Watch for breathing movements.

3 To find out in what ways a living frog differs from nonliving matter, tabulate observations on a living frog and corresponding characteristics and activities of a nonliving object. Attend especially to indications of sensitiveness. Look for indications of breathing and for the manner of breathing; for differences in behavior in the water and in the air; for the use of feet in swimming, in jumping; for ways of getting and eating food.

4 To observe cells, tear a bit of the thin skin from an inner layer of an onion, place it on a microscope slide in a drop of water, lay a cover slip over it, and examine under the low power of the microscope. To stain the tissue, touch a drop of ink to the edge of the cover slip.

By a similar procedure observe other plant cells—for example, a bit of the underskin of a leaf; some pond scum; some green-slime scraped from a piece of wet bark; some yeast cells from a crushed bit of yeast cake; small leaves from peat moss and from elodea or other water plants; the skin of a potato; or the skin of a flower petal. In most cases it will be possible to make out the cell walls, the nucleus, and greenish bodies called chloroplasts.

Examine groups of cells from various animal sources. Take scrapings from the inside of your own mouth or that of a frog, or other animal.

Examine a culture of *Ameba proteus* or of *Chaos chaos*. Note the forms, numbers, and movements of the pseudopods. What seems to be going on just inside of the forward-moving tip? Look for changes in direction of movements; for the engulfing of food material. Compare the form and structure of the ameba with other cells that you have studied.

QUESTIONS

1 What qualities distinguish living from nonliving material?

2 How does a living animal differ from one that has ceased to live?

3 In what ways does a living plant resemble a dead one?

4 In what ways do plants move?

5 In what respects is the structure of a living object different from that of a nonliving object?

6 In what respects is the growth of an icicle like the growth of a living organism?

7 How do movements of living things differ from those of nonliving objects?

8 How does the irritability of living things differ from the sensitiveness of nonliving objects?

9 How does a living plant resemble a living animal?

10 How does a living organism differ from a machine?

11 What are some of the specialized activities of cells in complex organisms?

CHAPTER 2 · HOW CAN WE KNOW THE DIFFERENT KINDS OF LIVING THINGS?

1 How many different kinds of animals are there in the world?
2 What is meant by saying that the dog is related to the wolf, or that the lion is related to the tiger?
3 In what sense is one species related to a different one?
4 Can the animals of different species breed together?
5 How can we tell a weed from a useful plant?
6 Why do we class some animals higher and others lower?
7 What do we need to know about a plant or animal before we can tell in what class to place it?
8 What is the easiest way of finding the name of a new or strange plant or animal?
9 Why are Latin names used for plants and animals instead of common names?
10 Who needs to know all the scientific names?

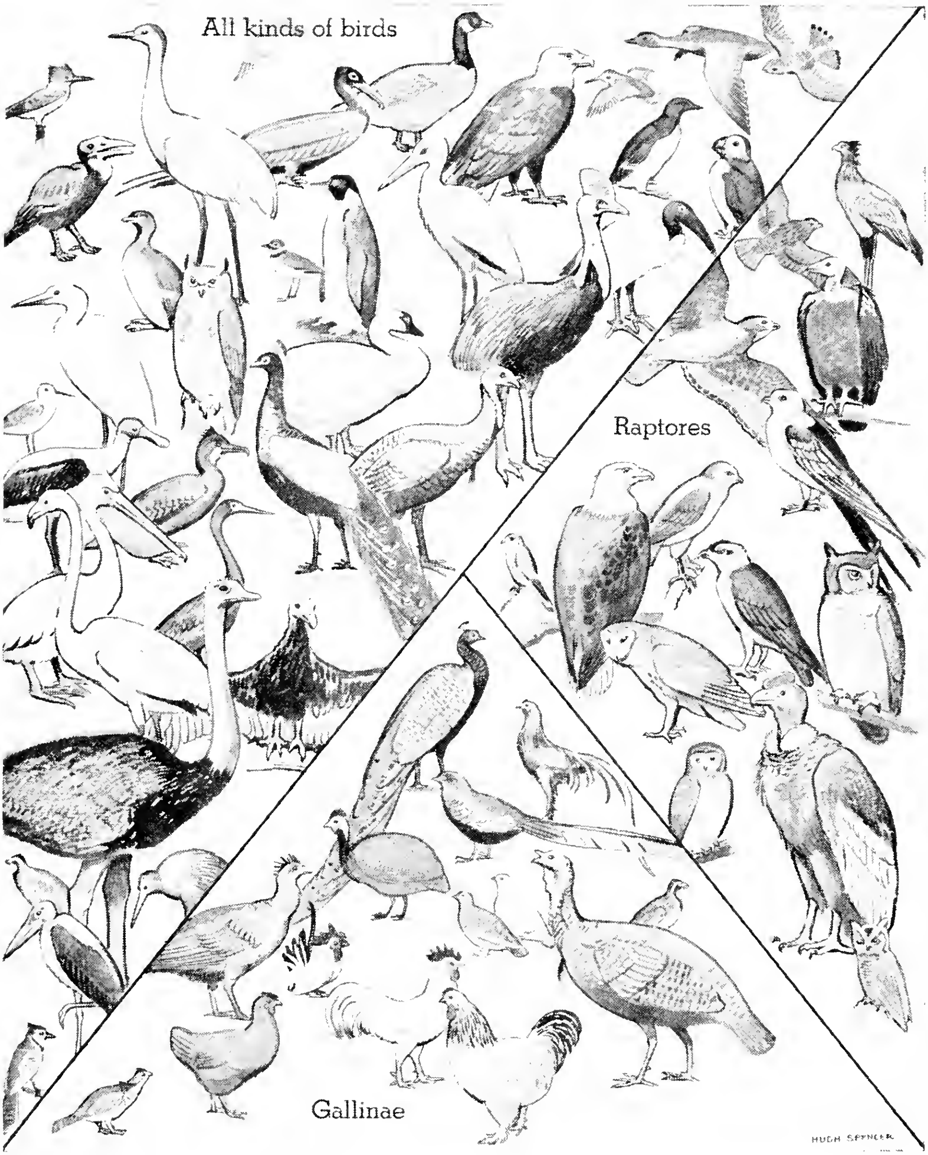
The world is so full of a number of things that we should be very much confused if we could not put them—and keep them—in some kind of order. About the first question we ask regarding a new and strange object is "What is that?" As we grow older, we want to know more than the name. For the new and strange thing is in some ways like whole groups or classes of objects we have known before, although it differs from them in some ways too. In time we learn to say, that is a *kind* of deer or sheep, that is a *kind* of daisy: each novelty is one of a *class* which we already know.

The grouping or sorting of objects is necessary for making order out of our world. The naming of objects is necessary for keeping order. The better we sort and the clearer we name, the better we can manage the great heap which would otherwise be chaos.

How Is Sorting Started?

Naming before Sorting We name common things so that we may *communicate* about them with one another. And naming is probably an important part of *thinking* about things. At first the child becomes acquainted with separate objects—this plate, mother, that bottle. He usually receives a separate name for each particular person. Later he calls many separate, but similar, objects by the same name: all chairs, all cats, all trees, all persons.

We use one name for many distinct objects because they appear enough alike to let us take one for another. And for many practical purposes one

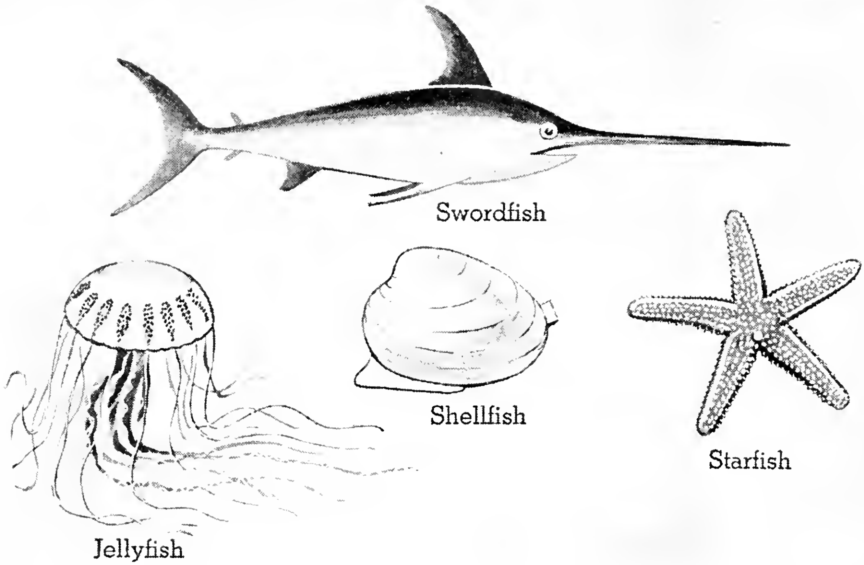


ALL BIRDS LOOK ALIKE, BUT—

At first, all birds may look alike to you, except for differences in size or color; the swallow is as much bird as the ostrich or penguin. As you meet more and more kinds of birds, you come not only to distinguish them or to recognize them by name, but also to notice that they can be grouped into several families or orders—those with flat bills, for example, and those with pointed bills; or those that are more or less like the familiar hen and those that resemble in many ways the hawk or the eagle

FLOWERS ARE FLOWERS, BUT—

At first all flowers, or blossoms, are just flowers, except for differences in size or color. A violet is as much flower as a "sunflower"—which is really a combination of hundreds of small "flowers". As we see more and more kinds of flowers, we not only distinguish different kinds and recognize them by name, but we notice that they can be grouped into several classes or families—those with petals arranged around a center, for example, and those that have right-and-left halves; or those that are more or less like daisies and sunflowers, and those that resemble in many ways the flower of the sweet-pea



GENERAL NAMES AND SPECIAL NAMES

To class these animals as "fish" is to say that they are alike in some way. But they are alike only in the fact that they all live in water. The first part of each compound name tells us that each of these "fish" differs in some special way from "fish" in general

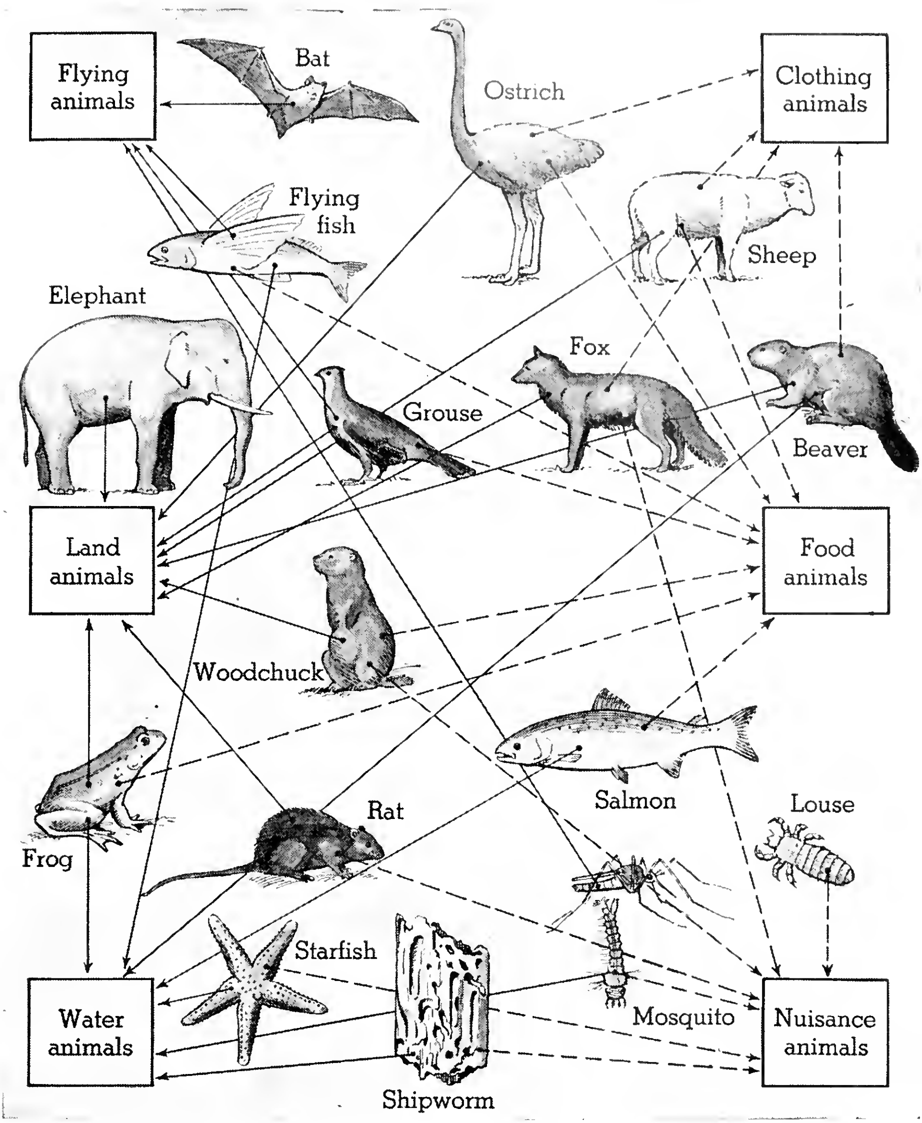
glass of milk, one spoon, or one tree may serve as well as another. When we need to distinguish, we usually add something to the class-name: the blue chair, or the tree-with-the-swing.

We do not make up the names ourselves. We find most names already in use, and accept them without question. The name *tree* goes with a certain class of objects; the name *fish*, with another class.

Assembling and Separating[1] Sorting is a process of noting differences and resemblances at the same time. When we know a considerable number of birds or of flowers, we cannot help seeing that the birds are not all alike, or that the flowers are not all alike. We keep together all "birds", and under the label "flower" we keep together many other kinds of objects. Now we make distinctions among members of each class.

Next we keep apart those that differ enough to call for distinct names. Ordinarily we use an older class-name for the larger or *general* group, and then add a *special* name for the smaller subgroup. In this way we speak of blue-bird, black-bird, snow-bird, and so on; or we speak of apple-tree, pear-tree, or cone-tree.

[1]See No. 1, p. 44.



WAYS OF SORTING

We can classify animals according to our concern with them or according to their ways of living. Either of these classifications is useful and sensible. But neither is of general value or inclusive. Some people would not consider lobsters or frogs "food" animals. The mosquito and the frog spend a part of each lifetime in the water; but one is for the rest of its life a "flying" animal, the other is in part a land animal. A sheep is both a "food" animal and a "clothing" animal; a fox is both a clothing animal and a nuisance. What is a good classification?

What Is the Basis of Classification?

Many Bases We could classify living things, as we classify stamps and ships, in many different ways. One of the oldest and commonest methods of sorting animals is according to *the way they concern us.* There are *food* animals, *fur* animals, nuisances. Or we might classify animals according to the regions or the conditions in which they live—arctic animals and tropical animals; mountain animals and lowland animals; land animals, air animals and water animals.

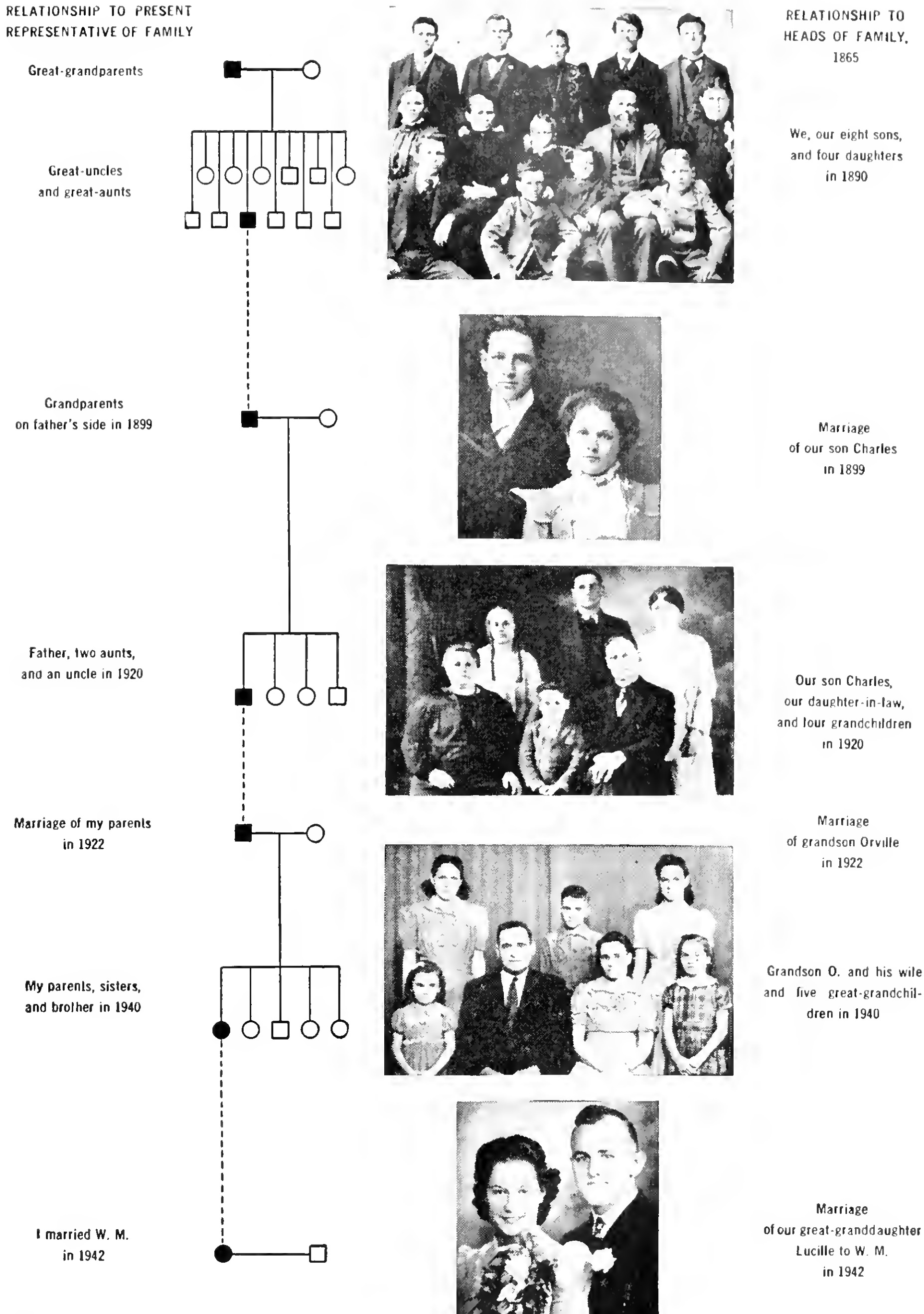
Each basis of sorting may be useful. But the first plan suggested would bring together sheep, chickens and salmon; or sheep, foxes and buffaloes. It would bring together mosquitoes, rats, foxes and shipworms. The second plan also has its uses, but it brings together birds, bugs and bats, which all fly; or whales, fish and oysters, which live in water; or spiders, elephants and penguins.

A good classification has a place for each "kind" and it avoids counting any particular "kind" more than once. A land-water classification would have to place the frog in one group as a tadpole and in the other group as an adult. If we had a useful-harmful classification, the farmer and the furrier could not agree about the fox.

Choosing a Basis for Classification In classifying living things today, we consider not merely their appearance or their uses to us, but all that is known about them. Separating all organisms into plants and animals is very old and appeals to common sense. We recognize that in a general way animals are more active than plants, and more sensitive to changes in the

This Swedish botanist and explorer developed a system for classifying plants and animals which served to bring order out of great confusion. Linnaeus believed that every species was separately created, but saw similarities among species which he placed in the same genus. He grouped genera into orders and orders into classes. He also devised the binomial, or two-name, method of naming species in use today and made a place in his system for every known plant and animal, including man. His work stimulated the search for new species, and laid the foundation for the comparative study of living things

CARL LINNAEUS (1707–1778)



Simon M. Schwartz

RELATIONSHIP THROUGH DESCENT

Individuals are "related" because they have some ancestors in common. All "related" persons of today might trace family connections to a couple of parents somewhere along the line away back in time (□ = male; ○ = female)

surroundings. At the same time, we know that some animals remain fixed in one spot and move very little, whereas some plants are rather sensitive or move visibly (see illustration, p. 257). Animals usually depend upon other organisms for their food, whereas most of the common plants construct food out of raw materials.

In addition to fairly distinct animals and fairly distinct plants, there are many living beings that we cannot so surely classify as either plants or animals. The bacteria and the "slime molds" belong in this borderland.

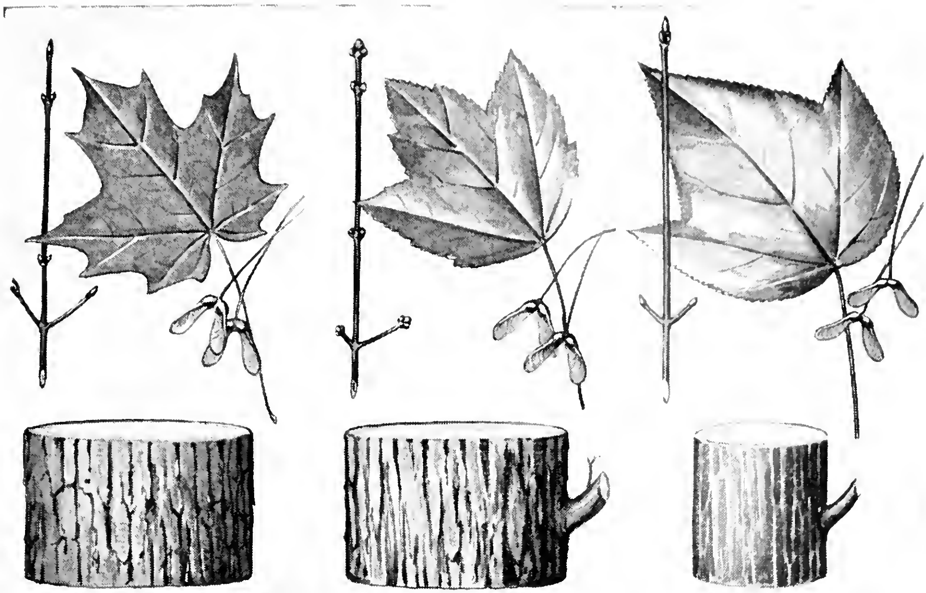
Among plants, as well as among animals, we find some species that we consider "higher" or more complex than others. Thus we think of an insect as higher than a worm or of an oak tree as higher than a palm. We cannot place all the known plants in one series and all the animals in another series, running from the simplest or "lowest" to the most complex or "highest." That would be like trying to arrange all people in a straight series from the worst to the best, or from the smallest to the largest. We take account of degrees of complexity, as well as types of structure.

Why Must There Be So Many Names?

Discriminations Each human being is important enough to have his name distinct from all others. We do not have an individual name for each particular object—each chair, each strawberry or mosquito—because in most cases it is enough to use a class-name. For most people, most of the time, mosquitoes are mosquitoes, wheat is wheat. Yet it is sometimes necessary to distinguish. Some mosquitoes transmit malaria, some do not. *We need a new name whenever we make an important distinction.*

Double Names We use double names every day in speaking of persons—Sam Brown or Sally White. Such names consist of the family name and the individual, or personal, name. We also use double names to distinguish entire groups that have some resemblances, as blue-birds, black-birds, and so on. The plan of using *binomial* or two-name designations for all species, or kinds, of plants and animals was introduced in 1735 by the Swedish naturalist Carl Linnaeus (1707-1778). Thus he labeled man *Homo sapiens* (man-wise), and a certain frog *Rana virescens* (frog-greenish).

What Is a Species? When we speak of a "family" of human beings —the Franklins or the Hills—we include the idea that the individuals are *related*. The Hill boys and girls have the same father and mother. The father of their cousins and their own father are brothers. They have also grandparents and other cousins with different family names. We say that these are related to the Hill children on the mother's side. But we think of all the Hills and all the millions of other human beings as of the same *kind*.



Sugar maple (*Acer saccharum*) Red maple (*Acer rubrum*) Striped maple (*Acer pennsylvanicum*)

GENUS AND SPECIES

After you know a maple from an elm or an oak, you may continue to give the name "maple" to trees that are in many ways distinct. When you get to know sugar-maples, for example, from red-maples, and after you find them to remain consistently like other sugar-maples and consistently different from red-maples, you attach to the general or genus name qualifying or species labels. From the time of Linnaeus scientists have systematically used double names—a general name and a special name—for every species. For example, we use the Latin "genus" name Acer to denote maple, and the Latin "species" names saccharum, rubrum, and pennsylvanicum to designate particular kinds of maple

When we say that all mankind make up one species,[1] *Homo sapiens*, we mean that all human beings alive today had the same ancestors *thousands of generations back*. When we say that all the greenish frogs are of the species *Rana virescens*, we mean that they are all descended from a common ancestor. Of course we cannot "prove" this through family records, for either frogs or men. But we have good reasons for assuming that there is this connection between members of a species. At any rate, the usual idea of a "species" is "all the individuals are enough alike to let us assume that they descended from a single pair."

How Are Different Species Related? Linnaeus recognized that only by using double names could we have distinct names for each species.

[1]The word *species* has the same form in the singular and plural.

Wood frog	Grass frog	Bullfrog	Spotted salamander	Common toad
(*Rana sylvatica*)	(*Rana pipiens*)	(*Rana catesbiana*)	(*Ambystoma maculatum*)	(*Bufo americanus*)

RELATED GENERA

The grass frog, the wood frog, and the bullfrog are distinct species of the genus Rana, the Latin name for frog. Frogs and toads are grouped in the same family. These and other genera, together with the salamanders and other "relatives", make up the class Amphibia—animals that live both on land and in water

When we ask a question like "*What kind of frog . . .?*" we already say that "frog" is a general name including two or more species. Such a group of species we call a *genus* (plural, *genera*).

As in all classifying, we sort animals and plants on the basis of resemblances and differences. And we consider them "related" according to the degrees of resemblance. Thus we speak of frogs and toads being related, as of the same *family*, although we do not have to decide what species was their common ancestor, or even whether they actually had any common ancestors. In fact, Linnaeus himself believed that each species had existed as we see it from the very beginning.

How Are the Larger Groups Related?

Kinds of Divisions The main branches of both the plant "kingdom" and the animal "kingdom" are called *phyla* (meaning "tribes"; singular, *phylum*) after Linnaeus's plan. These phyla are divided into *classes*.[1] In some phyla there are but a few classes; in other phyla there are many. In some phyla the classes are rather distinct; in others there seem to be "related" forms that are not so easily grouped by their characters. Accordingly,

[1]Note that here the word *class* is used in a very special sense, meaning one of the chief divisions of a phylum, not merely any grouping whatever for which we may have a name. Note also the special use of the word *family* in classifying plants and animals.

it is sometimes convenient to have another separation between the phylum-division and the class-division. So we have two or more "sub-phyla." There may also be "sub-classes." In fact, we may make a sub-division wherever we find it convenient, or wherever the material is sufficient in amount and variety. For we need not suppose that a "class"—like *bird* or *fish* or *insect*, for example—exists and merely waits for us to recognize it. In a sense, all our sorting is artificial, although it is based on facts that we can actually observe in natural objects.

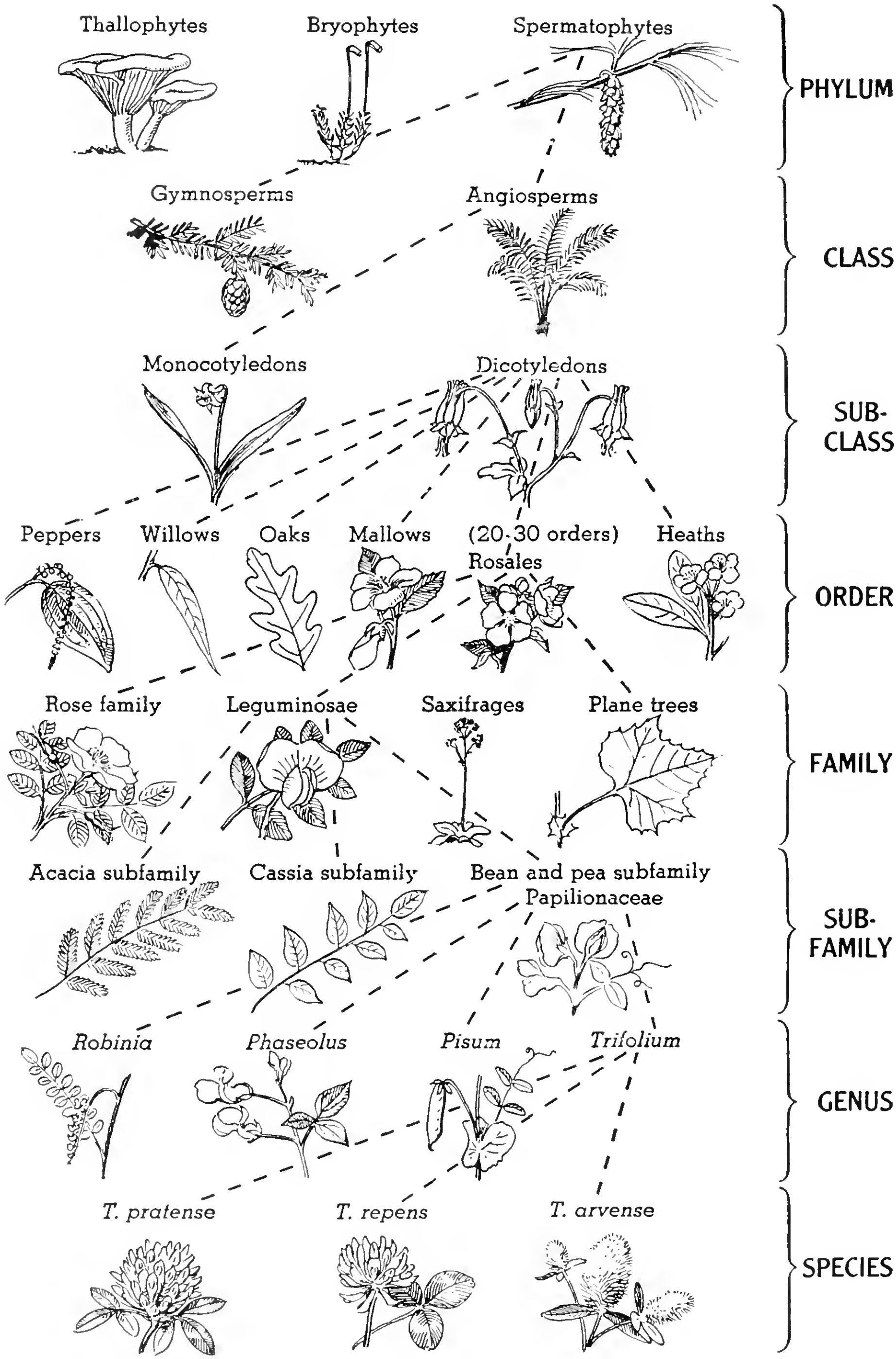
The "classes" have been broken down into "orders," and these into "families." Within the families are the genera (singular, genus), each with a variable number of species. As in the case of the species themselves, each of these divisions is determined by the resemblances and differences *that we can observe.* There can be no rule as to how much difference it takes to set up a new species, or how many species should go into a genus. New species are constantly being described, and older groups are constantly being recombined.

A General Scheme The names we give to the main divisions and subdivisions in our schemes of classifying organisms are arbitrary or conventional. It is nevertheless well to use them in the special senses of the taxonomists instead of the informal everyday sense. Thus we speak of the cat *family*, the dog *family*, the *class* birds, the *order* butterfly, the *phylum* chordates, and so on.

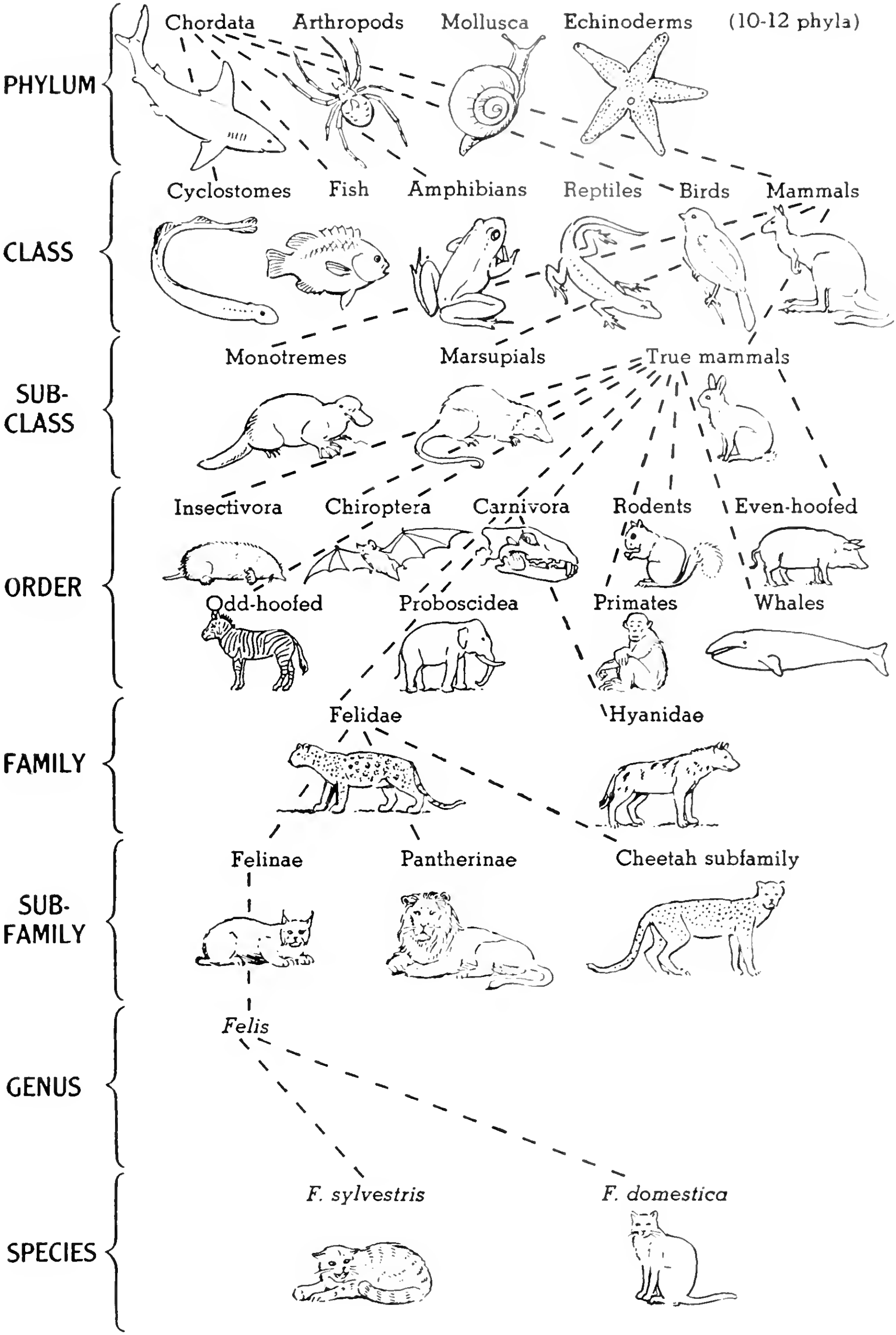
Since we sort according to physical characteristics, we naturally cannot use the same basis for classifying plants and animals. Linnaeus classified plants primarily on the flowers and other structures associated with reproduction. He classified animals chiefly on the more obvious structural characteristics and on their modes of locomotion and food-getting. Among both plants and animals, however, the successive subdivisions are given the same names (see pages 40 and 41).

Using Classification[1] No person can ever know all the plants or all the animals. By observing and comparing different species, an individual could in a lifetime learn to know several thousands of species by name. At the same time, he could learn to recognize at a glance the class, order or family in which to place many thousands of other species that he had never seen before. This is not as difficult or mysterious as it sounds, for everyone does just that every day without much effort. Suppose you see a kind of "animal" that you have never seen before. You recognize it at once as a "kind of bird" (class). Or you might say offhand, "That is a kind of parrot" (order) or "a kind of woodpecker" (family). You might not guess that the peacock is classed as in the "same family" as the common fowl, but you would guess that the duck and the goose are "related".

[1]See Nos. 2 and 3, p. 44.



THE MAIN SUBDIVISIONS OF THE PLANT WORLD



THE MAIN SUBDIVISIONS OF THE ANIMAL WORLD

Nobody should try to memorize the tables showing the chief types of plants and animals (Appendix A). The best way to use these tables is to refer to them and to the "trees" (frontispiece) whenever a new species of plant or animal comes to notice. Before long one can then recognize the place which each of the more common forms has in the entire scheme.

After becoming familiar with representatives of the main branches, or phyla, one can easily see the meanings of the "definitions" for most of these groups. The more common classes and families are also easily learned. Many are astonished and pleased to find that although the "scientific" names appear at first outlandish and "difficult", they are no harder to pronounce than are those of our common language. Nor are they hard to remember if one takes pains from the first to find out what they *mean*.

In Brief

We classify living things in various ways for different purposes.

We usually group together under one name individuals or objects that are equivalent or interchangeable.

The number of subdivisions we name depends upon our need to distinguish, or discriminate, among similar forms.

Any scheme of sorting must bring together individuals or groups of individuals according to what they have in common, and exclude those which differ, even though they show superficial resemblances.

We do not usually invent names for common groups, but accept those already in use.

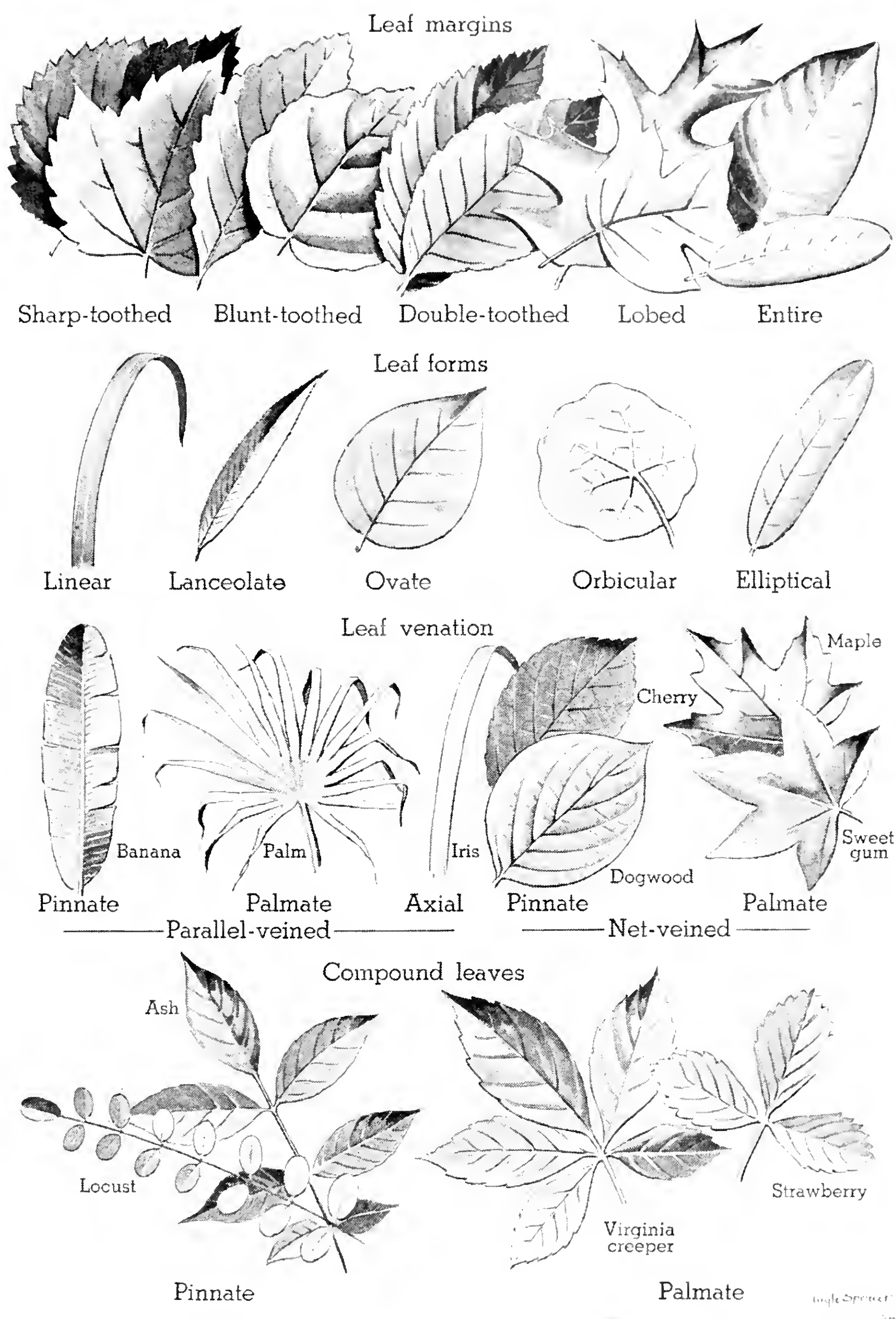
We divide all living forms roughly into the plant "kingdom" and the animal "kingdom".

Both plants and animals are classified according to a branched arrangement in which the larger groups are progressively subdivided into smaller groups.

The classification tree branches first into phyla, then into classes, then orders, then families, then genera, and finally into species.

A species includes all the individuals that are so much alike that we feel warranted in assuming that they descended from a single pair of ancestors.

We consider different species related to each other according to the degree of resemblance among them.



VARIETY IN LEAF CHARACTERS

EXPLORATIONS AND PROJECTS

1 To find a basis for classifying leaves, collect enough leaves of about 25 different plants to supply one of each kind for each pair of workers. Examine the leaves to find details of form, coloring, margins and arrangements that suggest resemblances and differences. Select what seems to be the most obvious character that will serve to divide all the leaves into two groups. Record the names of all the species placed in each group by this first dichotomy, or "forking", and also the basis for the separation.

Within each group of leaves, select a second prominent characteristic, and divide each pile into two more piles according to the new criterion. (It is sometimes possible on this second sorting to use the same criterion in dividing both piles.) Record the basis for separation used and list the species in each of the four groups.

Continue subdividing until the leaves left in each pile appear to have enough in common to be considered as of the same family or "kind".

Check on the adequacy of the criteria and on the consistency of the work by noting whether all the oak leaves, for example, did get into the same pile, and all the clover leaves into another single pile; and by noting whether leaves of different kinds came into the same group.

From the records of this procedure, it is possible to construct a "key" with which one could quickly identify any of the leaves included.

2 Select a spot where a variety of living plants can be found and picked. Work in squads or committees, each with definite plants to find and to identify correctly—algae, fungi, lichens, mosses, liverworts, ferns, horsetails, club mosses, conifers, monocots and dicots. After each committee has verified or checked its collection, spend the remaining time hunting additional specimens of special interest.

3 Collect from a brook or pond numerous living animals by pulling a dip net through the clusters of aquatic plants growing there. Bring these living specimens to your laboratory in vessels of water. Place them in shallow glass dishes for easy observation. Find, sketch and name as many different kinds of animals as you can. Group them according to outstanding characteristics that you recognize.

QUESTIONS

1 What is the use of naming the various forms of living things?

2 What is the use of classifying the various forms of living things?

3 What must a scheme of sorting do if it is to be of practical value?

4 What are some of the common bases used in grouping plants or animals for specific purposes?

5 What bases are used for grouping plants or animals in the most widely accepted scientific scheme of classification?

6 What is meant by a species?

7 What names are used to designate successive subdivisions, or branches, in the classification of plants and of animals?

8 Why is it not sufficient to use common names for different kinds of plants and animals?

CHAPTER 3 · HOW DOES MAN DIFFER FROM OTHER LIVING THINGS?

1 What is the same in other animals as in ourselves?
2 How can we compare the human body with plants?
3 Are the insides of other animals like our own?
4 Which animals are least like human beings?
5 Have any animals exactly the same number of bones as we have?
6 Do drugs act on other animals as they do on us?
7 Are there any sicknesses that are the same for animals and for people?
8 Can animals reason?
9 Have any animals as much brain as human beings?
10 Some animals have keener hearing or keener smell than we have: are any of our senses keener than those of other animals?

What a piece of work is a man!
how noble in reason! how infinite in faculties!
in form and moving how express and admirable!
in action how like an angel! in apprehension how like a god!
the beauty of the world! the paragon of animals!—*Hamlet*, Act II, Scene ii

Each person is one of many billions of natural objects that make up our world. Each one is in a sense unique: there is no exact duplicate of him anywhere. Yet, different as one person is from the next, there is the class "human beings". Certain qualities and characteristics we all have together, and among all the many classes of objects man stands out distinct.

To ask how man differs from other living things is to recognize that man in many ways resembles other living things. Is man then like a fish, or like a flower? What is it that all living things, including man, *do*? Which living things are most like man? What is unique about mankind?

What Living Things Are Most Like Man?

Basis for Comparison[1] Our notions of "life" come to us from what we ourselves do and experience. It is therefore most helpful, in order to get our bearings, to compare ourselves with those forms of life that resemble us most—the vertebrates, i.e., animals that have a backbone.

[1]See No. 1, p. 59.

Like the bodies of other vertebrates, the human body has a brain-box at the front end of the backbone. Comparing our arms and legs with the limbs of four-footed animals shows a remarkable correspondence in detail, bone for bone[1] (see illustration, p. 48). The resemblances extend to the bones of a bird's wing or the flipper of a whale (see illustration, p. 49). Muscles, blood vessels, brains and nerves, kidneys, reproductive organs, sense organs, and digestive organs of all vertebrates have much in common; and the human systems of organs fit the same general pattern.

Man and Other Mammals[2] The five classes of vertebrates are represented by a perch, a frog, a turtle, a turkey, and a squirrel. When we say that "man is a mammal", we mean that *man has all the qualities which mammals have in common.* That is not the same as saying that man has the qualities of *all* the mammals, which is, of course, not true. Man has qualities that no other mammal has; every mammal has qualities that no human being has. Man cannot climb trees like monkeys or squirrels, nor live on grass like sheep and cows, nor cut through trees with his teeth like the beaver. But man is able to do what all these and other mammals also do—*in common.* He sees with the same kind of eyes, pumps blood with the same kind of heart, breathes with the same kind of lungs.

All the mammals are alike in having milk-glands, which furnish food to the suckling infant. They are all "warm-blooded". The newborn individual has the same general form as the adult. The skin is more or less covered with hairs, at least during part of life. In all these ways man is also a mammal, although he differs from all the other mammals.

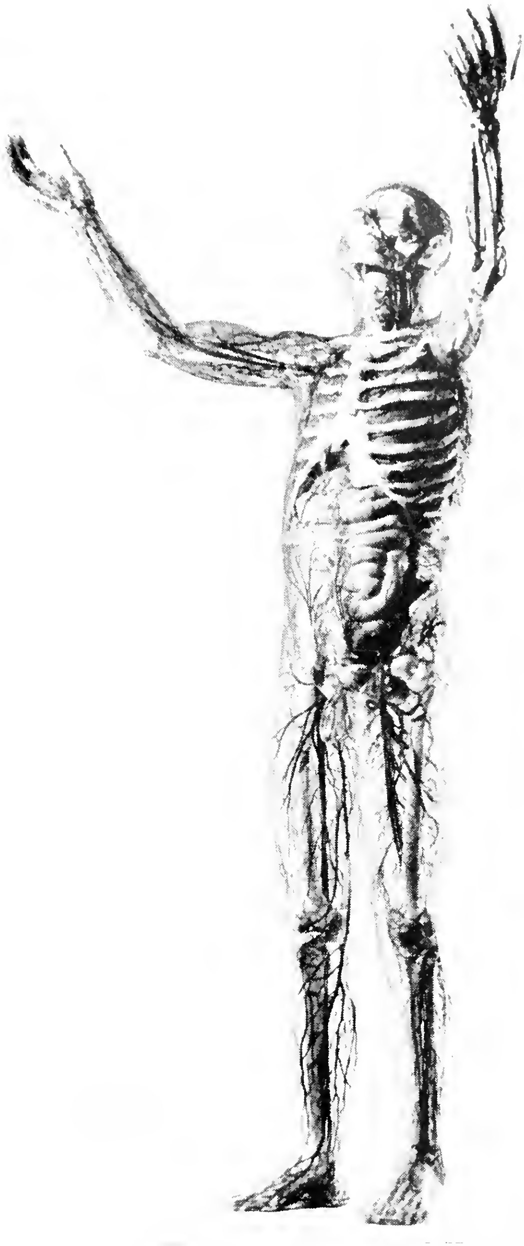
Various mammals can get up on their hind legs for longer or shorter periods. But none of them regularly walk erect, as human beings normally do. It has been suggested that by walking altogether on their hind legs, the ancestors of the human race freed their arms and hands for other activities, and were therefore enabled to develop these organs to higher skills. It is true, at any rate, that, if we judge from fossil remains, ancient man was an erect animal, whereas the front legs are used in moving about on the ground by all the other modern primates (the "first" order of mammals, which includes the apes and monkeys as well as man).

How Does Man Differ from Other Primates?

Hands and Feet The *differences* between man's front limbs and hind limbs are related to the erect walk. The front and hind limbs are distinct

[1]We must not be disturbed by so much attention to dry bones, nor attach to the bones any strange virtues. Scientists use bones in many of their comparative studies only because these structures can be more easily preserved and more accurately measured and compared than other parts.

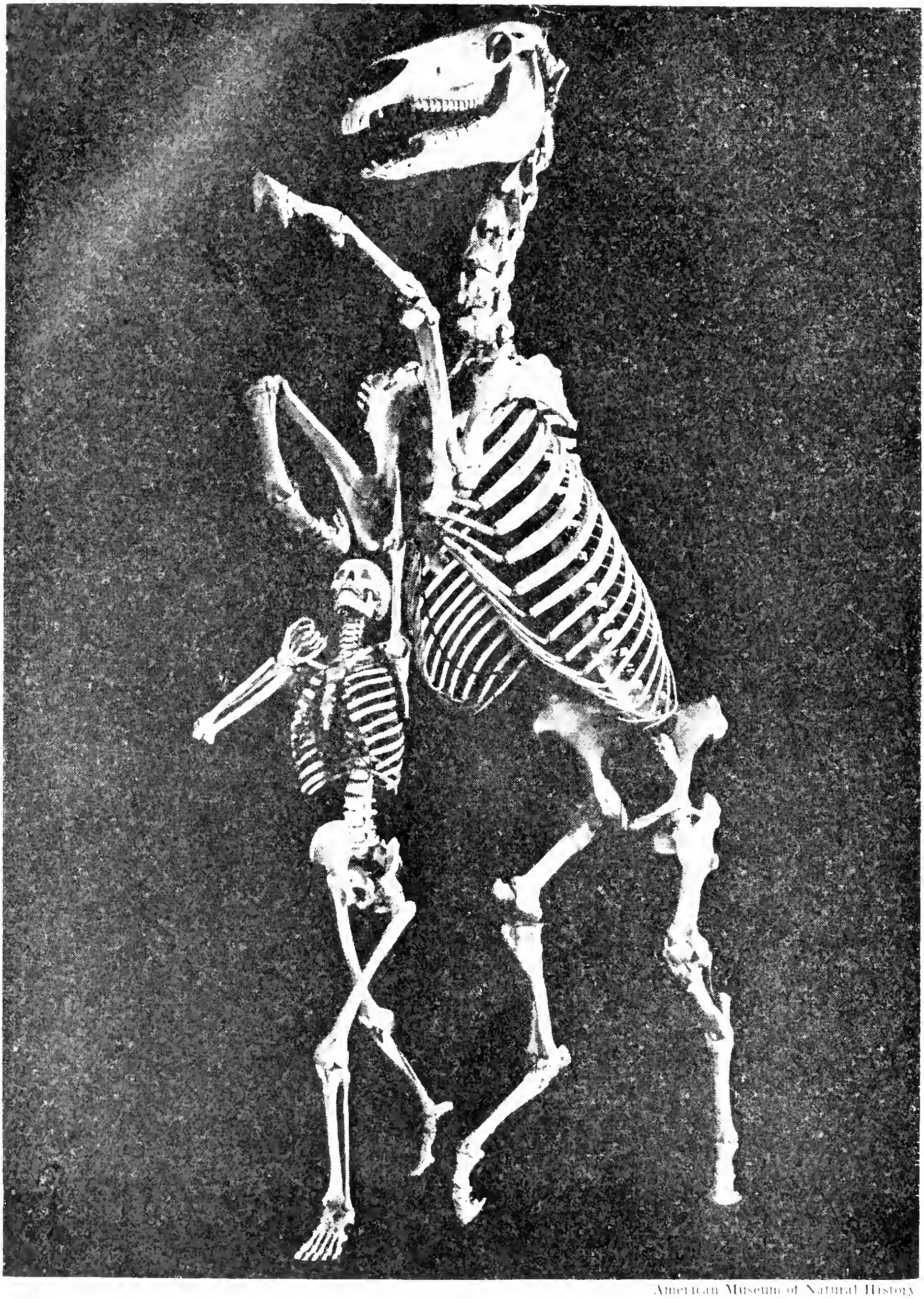
[2]See No. 2, p. 60.



American Museum of Health

"THE TRANSPARENT MAN"

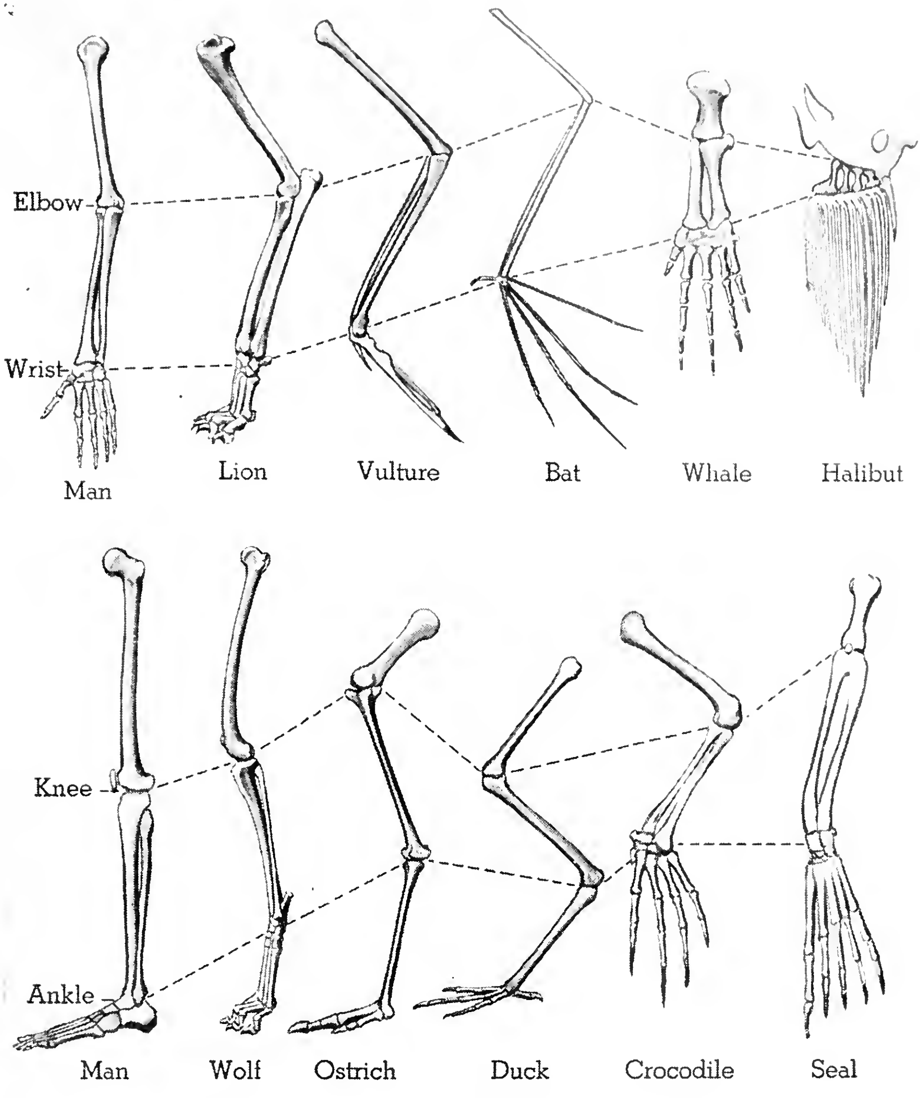
How man differs from other animals in reason, in imagination, in apprehension, in action, we should never discover by comparing organs and tissues and cells. But if we compare man's life with that of other animals, we may perhaps understand and appreciate man's resemblance to gods and angels



American Museum of Natural History

THE BODY PATTERN OF MAMMALS

In all vertebrates the brain and spinal cord are entirely incased in bone; the heart and lungs are enclosed within a lattice-like arrangement of ribs. There are two pairs of appendages



HOMOLOGIES IN FORE LIMBS AND IN HIND LIMBS OF VERTEBRATES

Walking, crawling, swimming, flying—all the various modes of locomotion found among backboned animals—are carried on by organs having the same fundamental structure

in other mammals too—in the bat, for example, or the kangaroo. But among the primates the human hand stands out, with its distinct thumb and the possibilities for fine "handling" of objects.

Galloway Roberts

THE HUMAN HAND

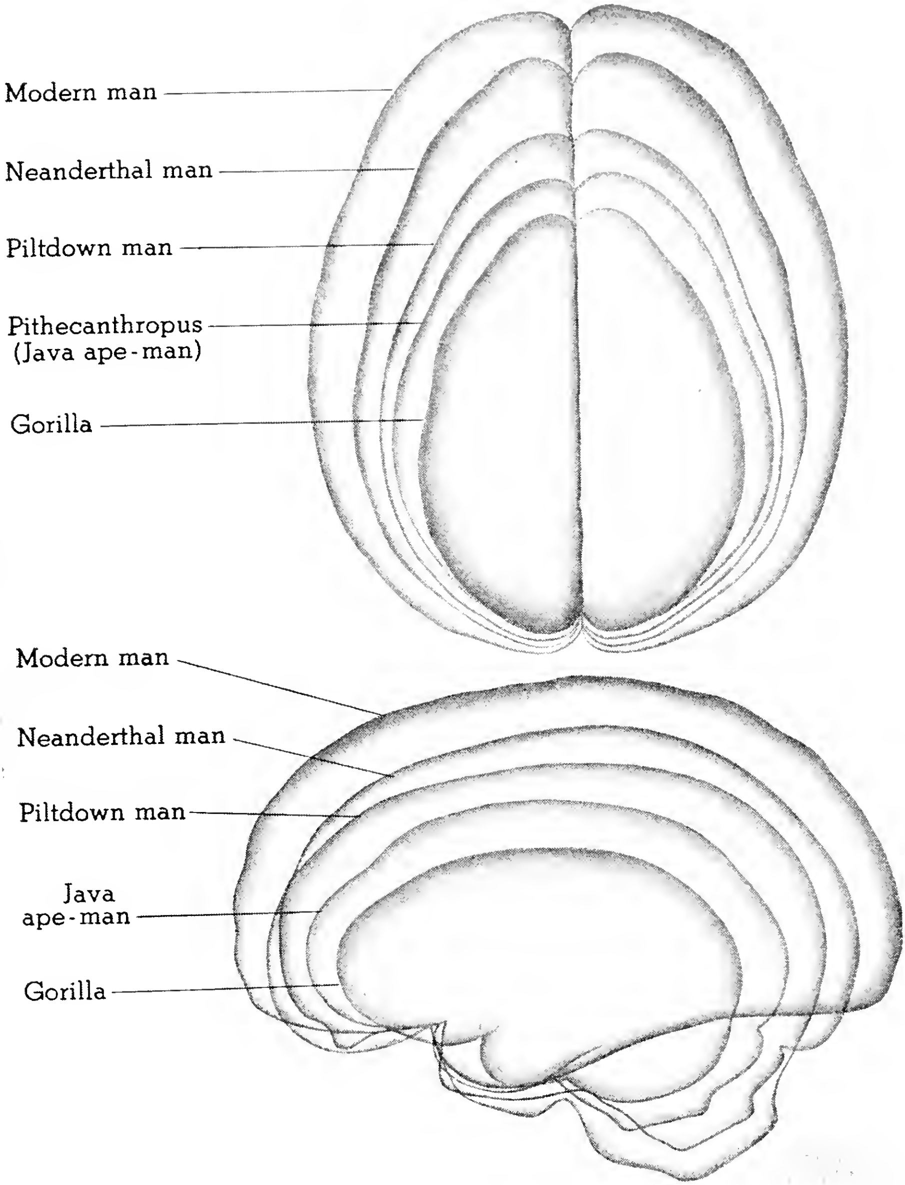
The versatility of the human hand is illustrated by the delicacy and sureness with which an artist or surgeon operates, or by the variety and power of movements executed by a workman

The Enlarged Brain A third characteristic of our species is the large brain, especially the forebrain (see illustration opposite). This brain is probably the most distinctive feature of man's whole life and history. For with this organ is associated man's capacity to learn from the past and to push his purposes and his plans farther and farther into the future (see table, p. 54).

The Chin and Mouth Distinctive of the human face is the well-defined chin (compare profiles in the illustration on page 52). We are impressed when we see a person who has either no chin or one that is exceptionally large. There is no obvious merit in this structure, although it is probably related to the workings of the jaw and the mouth. The lips as well as the teeth and the jaw show distinctive characteristics. These are related to the fact that man is the only animal that uses articulate speech.

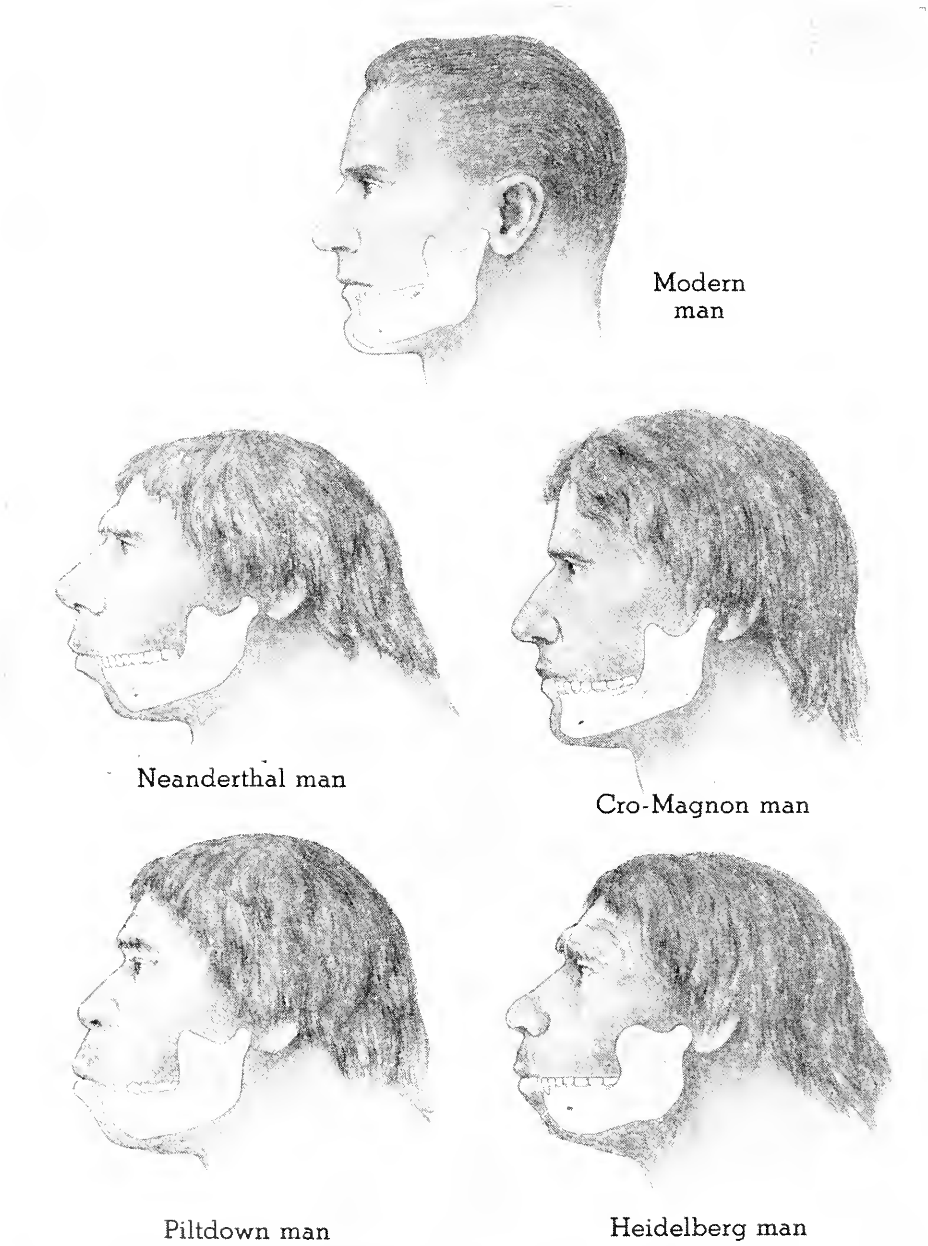
Speech[1] The hen can utter some twenty distinct sounds, and each one has a different meaning. Other animals communicate with each other through calls or cries. But in human speech there is more than a set of calls and cries. Human language consists of words, each with a definite pattern of sound. And these words are combined into *sentences* that express all kinds of ideas. Unlike the crowing and growling and snarling of other animals, human speech can be constantly adjusted to the changing and growing needs of the *thinking* animal. If you have a new idea, you can, by means of the language you have acquired, express it so that another person can

[1]See Nos. 3 and 4, p. 60.



THE BRAINS OF HUMAN TYPES AND OF OTHER PRIMATES

These five types of skulls and brains suggest relationships. The larger and larger brains correspond to more and more recent types, although they do not necessarily indicate straight lines of descent



MAN'S DISTINCTIVE CHIN

Fossil remains of human bones indicate progressive changes from the earlier chinless jaw of Heidelberg man, resembling that of the gorilla, to the less massive jaw, with its prominent chin, of modern man; and they indicate corresponding changes in the teeth

understand you. You do not have to invent new kinds of noises, and it is not often necessary to make up new words.

Man's Shortcomings Man is unquestionably the highest form of life. As a living machine, however, man is in many ways decidedly inferior to other animals. For example, his skin is much more tender than that of any other animal of his own size, and the hairy covering is not of much help. When he fights, his nails and claws are very poor rivals for those of cats, let us say. And his teeth are not nearly as formidable as are those of many other animals. His muscular development too is inferior when it comes to wrestling with a nonhuman enemy. When it comes to running, whether to capture a rabbit or a bird, or to escape an enemy, man would be easily outdistanced by many of the inhabitants of the forest.

Seeing, hearing and smelling are very helpful to animals for discovering enemies or food at a distance, and they are also of great value to man. Compared to other animals, man has a very good eye and a pretty good ear—though not one of the best for discovering faint sounds. But man's smelling ability is of very low rank.

Man and Apes A convenient summary of contrasts between the human family and the ape family was made by Dr. Henry Fairfield Osborn (1857–1935), the distinguished American naturalist and anthropologist. The comparisons on page 54 are based on fossil materials and other evidence of former life. They apply not so much to present-day human beings and present-day apes as to the ancient representatives of these two families.

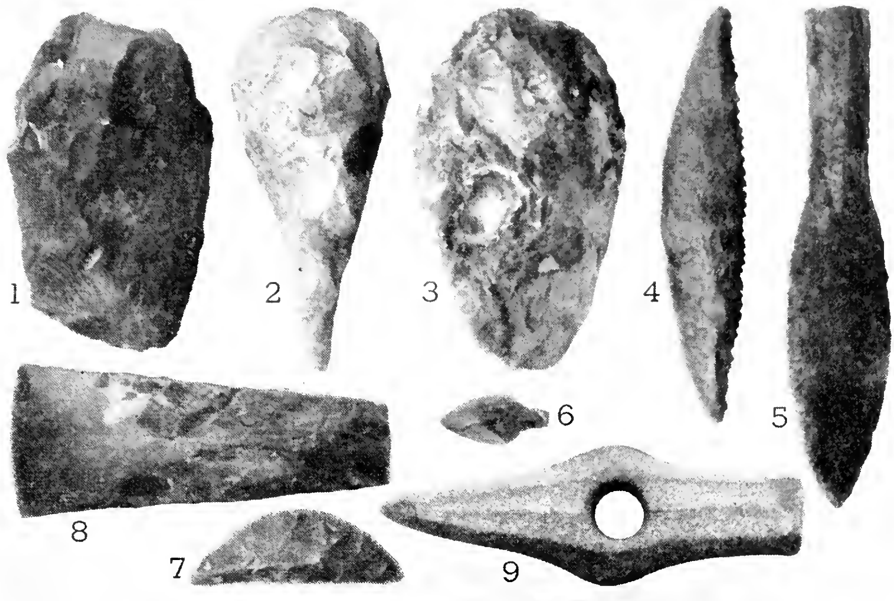
What Is Unique about Man?

Man's Advantages In spite of his various shortcomings, man has contrived to hold his own. And some branches of the species have become virtually masters of their environment. His hand and brain seem to have made up for all the important deficiencies.

Man has made up for his thin skin by borrowing the skins of other animals and by devising substitutes for skins (fabrics). He has strengthened his arm by means of sticks and stones. He has lengthened his legs—that is, increased his speed—by means of iron and brass. And with other contrivances, he has soared aloft, to rival the very birds. He has pushed his eyesight millions of miles beyond the surface of the earth, and has looked into the world of the littlest things. He can hear the footsteps of a fly (although he does not need to do so either for protection or for food). And he has caught vibrations through miles of space. In every direction man has made up for his organic weaknesses by using his thinking organ to guide his hand.

Contrast between the Human Family and the Ape Family

HUMAN CHARACTERISTICS	APE CHARACTERISTICS
1 Ground-living biped; habit adapted to rapid travel and migration over open country	1 Tree-dwelling; four-handed; habit adapted to living chiefly in trees
2 Development of the walking and running type of foot and great toe	2 Quadrupedal habit followed when walking on the ground
3 Use of legs for walking and running	3 Use of legs in tree-climbing and limb-grasping
4 Escape from enemies by vigilance, flight and concealment	4 Escape from enemies by retreat through branches of trees
5 Tree-climbing by embracing main trunk with the arms and legs, after the manner of the bear	5 Tree-climbing always along branches, never by embracing the main limbs and trunk
6 Shortening arms and lengthening legs	6 Lengthening arms and shortening legs
7 Walking and running power of the foot increased by enlargement of the great toe	7 Grasping power of the big toe for climbing, modified when walking
8 Use of arms and tools in offense and defense, and in the arts of life	8 Use of the arms for climbing; and for grasping food and enemies
9 Development of the tool-making thumb	9 Loss of thumb and absence of tool-making power
10 Adaptation and design of implements of many kinds in wood, bone and stone	10 Adaptation of the foot and hind limbs to the art of tree-climbing
11 Design and invention directed by intelligent forebrain	11 Design limited to the construction of very primitive tree nests
12 Progressive intelligence; rapid development of forebrain	12 Arrested development of intelligence and of brain



TOOLS AND WEAPONS OF THE STONE AGE

Relics of the Old Stone Age (1, 2 and 3) are roughly shaped. New Stone Age man had learned to chip his flints skillfully (4, 5, 6 and 7). Later he tried to smooth and even to polish his stone creations (8 and 9)

Tools, Weapons and Shelter The natives of Madagascar say that if you throw a spear at a lemur, the animal will catch it and throw it back with deadly precision. Monkeys will crack nuts by pounding them against some hard object, and the gorilla will use a stick as a club in fighting. But probably no gorilla or monkey ever carried a club or a stone about with him to use in possible emergencies; and that is something that man has done. Even among the oldest remains of human activity are stones which men had chipped to serve as weapons or as tools (see illustration above).

Many species of birds and of other classes of animals build very neat nests—much neater, probably, than primitive man built in the treetops. But man has finally succeeded in building shelters so far beyond anything other animals have made that it seems ridiculous to compare them.

Fire What using fire has meant to man most of us cannot realize, for we take the benefits of fire for granted from childhood. Fire enabled man to get out of the trees and live in caves or even in the open, for with fire he could keep the beasts away. It made available to him food that he could otherwise not use. And fire was probably helpful in many other ways from early times. Fire enabled man to wander from the tropics, so that of

all mammals man is the most widely distributed species. The dog is a close second, but only because man has taken him along.

Sociality How did human beings first come to use tools, fire and speech? These obvious advantages for human living are related to a characteristic of the species that does not show if we study merely the structure of the organism. This is the important fact that man always exists normally in groups. *Man is a social animal.*

There are of course other social animals. The bees and the ants at once come to mind. Wolves hunt in packs. The wild bison and other animals of the cow family roam in herds. Even very low types of animals form colonies with a considerable division of labor among the members (see illustration, p. 419). Social life among human beings, however, involves more than division of labor and the fitting of each individual to some special tasks. It involves the feelings which each individual has about others—his liking or disliking them, his admiration or contempt. It involves further what he feels about himself in relation to others—his fears, or pride, for example, or his envy. For man needs not merely supplies of food, or material comforts; he needs also a chance to deal with others in many different ways. *Man depends upon others, and others make demands upon him.* The fact that man prefers society to solitude has far-reaching consequences.

Animals living by themselves would have no use for "communicating". At any rate, the ability to use tools and fire and to speak, and social living are all closely related to man's superior brain.

How Is Man More than an Animal?

Preserving Experience Human beings can learn from experience, as can other backboned animals, and many lower classes too. They can learn certain things more quickly than other species. And they continue to learn through a longer stretch of years. Quite outstanding, however, is man's ability to *learn from the experiences of others.*

Experiments with many different species show that the apes and monkeys alone imitate what others are doing, although some birds imitate sounds. They seem to be the only ones, therefore, that could possibly learn from the experience of their fellows. Man, however, learns not only by imitating others, but also through direct instruction—the use of speech.

If a wasp should discover a new trick for catching caterpillars, and used it successfully in gathering food for her offspring, her acquired wisdom would die with her. For the eggs which she lays do not hatch out until after she is dead. Among human beings, however, the results of experience are carried on from generation to generation, through tradition and ceremonial. Savages preserve the art of making fire by teaching their young

American Museum of Natural History

CRO-MAGNON ARTISTS PAINTING THE WOOLLY MAMMOTH

Men living perhaps twenty thousand years ago left hundreds of paintings, clay figures, scratchings on walls, carvings in stone, etchings and carvings in horn. These records show that early man was able to imagine, to abstract, and to think

the solemn ceremony of fire-making. In the history of primitive peoples every good idea seems to have been preserved by means of ceremonial as well as by strict rules. In time, the race has managed to gather up a great deal of wisdom—as well as a great deal of what seems to us to be foolish or superstitious.

Imagining and Abstracting We can shut our eyes and call to mind a picture of something that we have once seen. We can recall particular scenes or particular pieces out of past experiences. These imagined fragments are not always selected. Something may "flash into the mind" unexpectedly. Perhaps something now present "reminds" us. This ability to imagine—to recall and reconstruct bits of past experience—is of tremendous importance, for our imagination enables us to use past experiences in dealing with new problems.

We can shut our eyes and see green grass, even when there is no green grass around. We can then think of *green* apart from the idea of grass. We can think of the *sweetness* of a fruit apart from the idea of the fruit, or apart from the color or the shape. In imagination, we detach the "qualities" of things that we have experienced from the things themselves; we *abstract*—that is, draw away from. Our thinking consists largely of such abstracting. We analyze our experiences or take them apart in imagination,

HUMAN CREATIONS

Marvelous is each living being in the use it makes of its structures and adjustments. The eagle and the hummingbird and the horse go as high and as far and as fast as their bodies permit. Man alone of all living things has vied with the gods in creating out of what he finds at hand new combinations of use and beauty and power, of delicacy and grandeur. Of all animals, man alone makes his dreams come true

and then combine the elements in new ways. We thus use past experiences in a way that no other living being can.

Creativity A dog will play with a stick, or a cat with a ball of yarn. Young children pile up blocks or put together bits of glass or wood. They try now one arrangement, now another. The various kinds of play may appear very much alike. Yet in children this kind of play includes the beginning of what we may call *creative* activity. For presently we see the child's play go beyond the mere handling of things.

In his imagination the child can abstract, or remove, the red of a cherry and place it on a piece of paper. One can remove (in imagination) the wings of an eagle and attach them to the shoulders of a horse or perhaps of a human being. Was it not by some such act that man eventually arose from the earth and soared into the sky?

We take for granted the bridges and wings that man has created to carry him across the chasms that would stop him in his wanderings. We take for granted the artificial caves that man has made for shelter. With his imagining and abstracting man has been creating new kinds of materials that nature never made, even new kinds of plants and new kinds of animals—actually *new species* (see pages 496–501). In recent times he has been trying to change himself over to meet his idea of what is good—not merely applying cosmetics and surface ornaments, but changing the

inner processes of his own body. Man has been correcting and re-creating himself, improving on his own "nature".

More than Beast Man must eat and sleep, like the very beasts. But it is foolish to say, "Man is only an animal", for as Shakespeare suggests, *man can do more.* Whoever can read these words senses that the ordinary person has in him something that shares in mankind's advances from beastliness and savagery. The advances have indeed been slow and uneven. There have been many setbacks. And it is true that within each man lies a cruel and cunning brute. But in addition, man is able to dream beyond all that is, and to strive toward the highest that his dreams can create. No other species can do that.

In Brief

The human body, with its parts, resembles in its structure the bodies of other backboned animals.

Man shares all the characteristics which are common to the members of the group mammals, and more strikingly those of the primates.

Man differs from the other primates in his erect walk.

Man's hands and arms differ more from his feet and legs than do the forelimbs and hindlimbs of other primates.

Man's hand and brain are the organs that have most distinguished him from other animals.

In several respects man is quite inferior to other animals.

The distinctive chin and mouth of man are closely related to the fact that he is the only animal that uses articulate speech.

Man always exists normally in groups; that is, man is a social animal.

Man learns from experience to a much greater extent than any other animal, and he preserves and passes on his experience from generation to generation through his language and social institutions.

Man's capacity to imagine, to abstract, and to create exceeds anything comparable among the other animals.

EXPLORATIONS AND PROJECTS

1 To compare the structure of various mammals, visit a zoo or circus where several different mammals can be observed, or visit a museum in which skeletons of several mammals and other vertebrates can be studied. Give particular attention to the general framework and limbs of the body. Identify structures which correspond to your shoulder and collarbone, upper arm, elbow, forearm, wrist,

hand and fingers. Also, identify the structures which correspond to your pelvic girdle, hip, thigh, knee, shin, ankle, heel, foot and toes. In what ways are the limbs of the various animals studied alike? In what ways are they consistently different? In general, do the forelimbs and the hind limbs of the various animals differ more or less from each other than do our arms and legs?

2 To compare man with the other primates, visit the monkey house at a zoo and compare the faces, arms and legs of the different primates with your own. What resemblances do you find? What differences? Are the hands and feet of the different monkeys more alike, or less, than are your own hands and feet? How does the posture of the monkeys resemble your own? How does it differ from yours?

3 To explore the ways in which human beings communicate, make a list of various ways in which we human beings can communicate with one another. Group these ways under the following headings: (*a*) means of expressing fear, pain, joy, and other emotions; (*b*) means of communicating through space; (*c*) means of communicating through time; (*d*) means of passing on experience from person to person; and (*e*) means of passing on experience from generation to generation. Compare your suggestions with those of others and summarize the observations in one or more general statements.

4 To study communication in various animals, examine reliable reports or personal observations of specific instances of communication among domestic or wild animals of any kind, or between members of two different species. Discuss the following critically: *How can we establish the fact that there has been communication?* How do the modes of communication resemble those used by human beings? How do they differ? How can we explain what happens in such cases?

QUESTIONS

1 In what respects does man resemble other living things? In what respects does he differ from them?

2 How do the various living processes of the human body compare with those of other animals? of plants?

3 How do the basic structures of man compare with those of the other vertebrates?

4 In what sense are the structures of living organisms adaptive?

5 In what respects is man inferior to other animals? In what respects superior?

6 How does man differ from other primates in structure? in capacities?

7 What are the outstanding advantages that man has in comparison with the other primates?

8 What is meant by the statement that man is able to deal with abstract ideas?

9 What is meant by saying that man is a "creator"?

10 How can we be sure that man is the only animal that makes his dreams come true?

CHAPTER 4 · HOW DO INDIVIDUALS DIFFER?

1 What brings about differences among people?
2 In what respects are all individuals exactly alike?
3 What characteristics of a person are important to his friends, fellow workers, neighbors?
4 What characteristics of a human being are important to himself?
5 Why are there different kinds of people in different parts of the world?
6 Are the distinctive characteristics of persons inherited by their children?
7 Has the human race improved within historic times?
8 Does a large head mean greater intelligence?

Humpty Dumpty, you may recall, was not sure that he would recognize Alice if he should meet her again since, like other people, she had an eye on each side of the nose, mouth across face under nose, hair on top of head, and so on. In some ways all of us are alike. In some ways all the members of a species or "kind" are quite alike. That is what we mean when we call cows "cow" and all pine trees "pine tree". Among thousands of distinct objects we take some to be of "the same sort"; that is, we emphasize similarities and disregard differences.

Individuals of a species differ from each other. Perhaps you have mistaken one person for another: the two were so much alike. But then you discovered your mistake. If all were exactly alike, however, you never could have discovered your mistake, nor would it have mattered. If you feel like making a gift to a friend, it does matter that you get it to the right person.

Each of us wants to be enough like others to be recognized as "belonging", as being "regular". But each of us wants also to be known for himself, for what is distinctive, and not be mixed up with a dozen or a hundred others, or even one other. Each knows himself to be unique. Of what does this uniqueness consist?

In What Ways Do People Differ?

Physical Differences[1] The people whom you know differ from one another in almost every way that you can observe—height, girth, coloring, the relative sizes of the various features of the face, the relative length of arms and legs and trunk. You distinguish your acquaintances not alone by their general appearance, but also by their voices—which means that the

[1]See Nos. 1 and 2, p. 74.

vocal cords are of varying proportions, and that the insides of their mouths vary in shape.

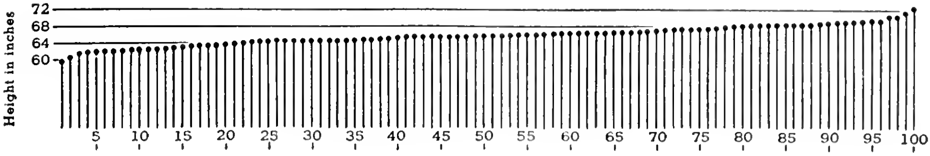
One hundred boys in a large high school all had their birthdays in the same month of the same year. The tallest boy was twelve or thirteen inches taller than the shortest. The heaviest weighed nearly twice as much as the lightest. These boys differed from one another in at least two characters—height and weight. Two of the boys might have been exactly the same in one respect, and quite different in the other.

If boys or girls, arranged in a row according to height, should all sit down on benches of the same height, some would then appear out of place. That is, people of the same height need not have trunks of the same length or legs of the same length.

Our acquaintances differ in the shapes of their eyes and in the colors of their eyes, which range from pale gray to almost black. Their hair ranges in color from pale yellow to black. Some have hair of various shades of red to brown that do not quite fit into this series from lightest to darkest. Some

LONG AND SHORT; THICK AND THIN

There is great variation in the shapes of people having the same height, and great variation in the heights of people having the same weight



VARIATION IN STATURE

When 100 boys of the same age stood in a row in the order of height, the tops of their heads formed a line like this row of dots. The middle part of the line was nearly horizontal; that is, there were several boys of almost exactly the same height

have fine, silky hair; the hair of others is coarse. The hair of some is straight; that of others is wavy, curly or kinky. Rarely do we find two individuals with exactly "the same kind" of nose or mouth or ears or chin or cheeks or lips.

Chemical Differences Skin-colors distinguish the large groups we call "races"—Caucasian, Mongolian, Negro, redskin, and so on. Color differences usually indicate chemical differences. There are, in fact, several distinct pigments in the human skin, hair and iris, and in corresponding parts of other animals. And these pigments are present in varying proportions. Even within any one "race" there are wide variations in the colorings, as well as in the intensity of pigmentation.

A person who has had the measles is usually unable to get that disease again: he is said to be *immune*. This change does not show in one's appearance, but is due apparently to some chemical alteration in the blood or in other juices of the body. People differ also in their original immunity, or resistance to disease. Thus, when two individuals are exposed to typhoid fever, one may remain unaffected while the other gets sick. On the other hand, one who is immune to typhoid may succumb to tuberculosis. Such facts indicate chemical differences among people.

Each of us knows some individual who suffers from asthma or hay

VARIATION IN FACIAL FEATURES

Whether we consider the form of any feature, such as the nose, mouth or chin, or the color of hair or eyes, or any other trait, we find endless variations in countless details

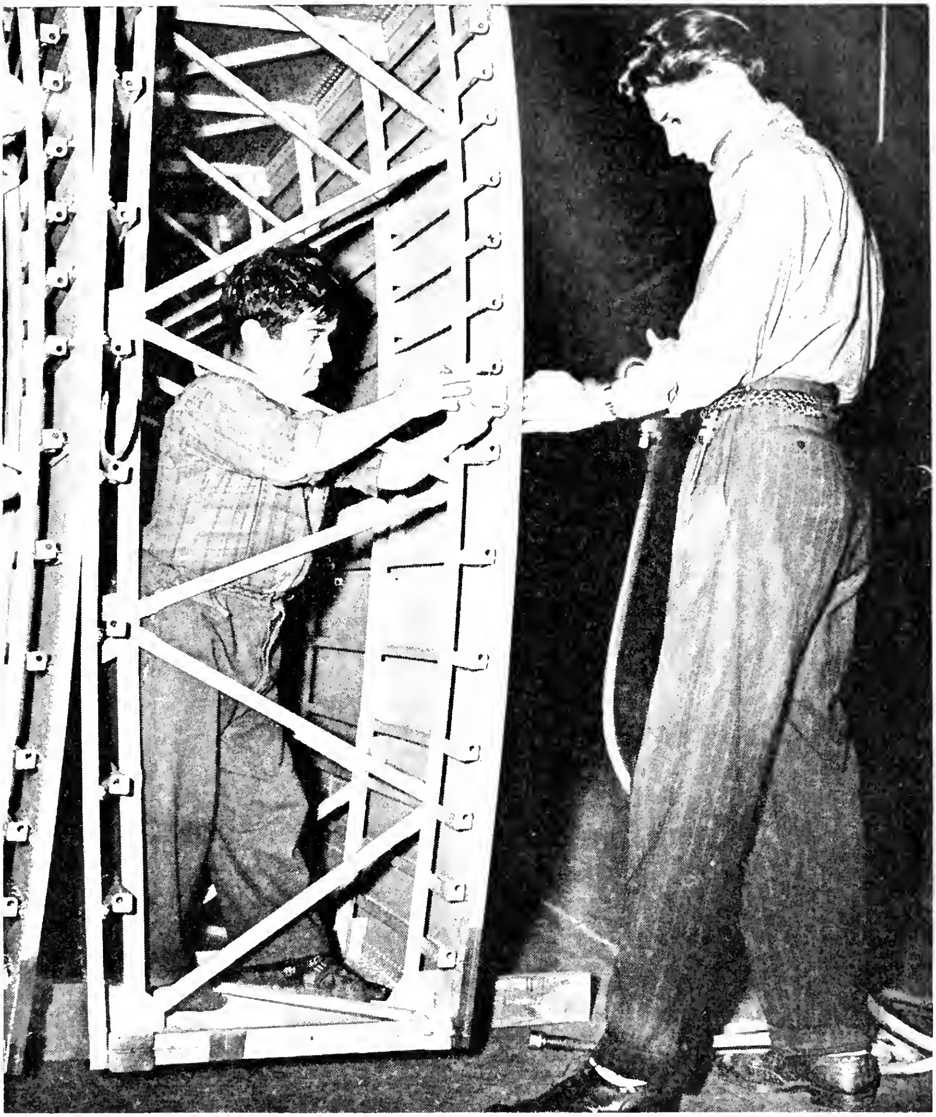
Press Association

RECOGNIZING A PERSON BY HIS ODOR

Here we make practical use of the fact that each individual differs from others chemically. We recognize persons by their appearance or by their voices or even by the "style" of their art or workmanship, but it takes a dog to smell a particular individual's "blood"

fever. Other members of the same family are immune. Why is it that "one man's meat is another man's poison"? In general, individuals appear to differ chemically as well as physically.

Organic Differences Two boys who appear to be equally well de-



Brewster Aeronautical Corporation

PHYSICAL CHARACTERISTICS AND SPECIAL PERFORMANCE

From among many different kinds of persons, we pick those having special qualities for carrying out special tasks. Sometimes we consider tallness or weight. Sometimes agility is more important, or endurance, or dexterity, or a quick eye

veloped physically set out on a hike, but after an hour one of them has to stop for a rest. Perhaps the two can do about the same amount of work in the course of a day, but one of them has to take his task in short units. Again, of two girls of the same height, one is decidedly slender; yet she

appears to have more endurance. We are familiar with differences in muscular capacity, as well as in ability to acquire various skills: one does better in basketball or hockey; another does better in tennis or in marksmanship.

In most of our work, games, sports and hobbies, we are constantly aware of differences among people. We select members for our teams, trying to get the best players, or the potentially best players. Then we assign each one to the particular task for which he is best fitted. Whatever qualities we consider of value, however, we seldom think of them as chemical and physical peculiarities in the materials and organs of people.

What Is Normal?

The One and the Many Twenty thousand people attend a great ball game. The players are carefully picked and trained. But nobody cares who the spectators are—except each one himself. For certain purposes, we are all alike. We are so many million mouths to feed, or so many customers, or so many passengers carried so many miles. Particular persons appear to be overlooked. In most cases, when something happens to one of these, nobody cares whether it happens to this one or to another—except the particular person himself and his immediate relatives and friends. For himself each one is somebody in particular. Each one feels himself to be unique: he wants to be himself and he can admit no substitute.

There seems to be a contradiction between wanting to be like everybody else and wanting to be different. If we were all actually alike in every respect, problems of personality would never arise. What you consider your *self* probably comes into being only as you discover that you are separate from and different from other persons. Yet you do not want to be so different as to be classed in-human, or even as super-human.

In everyday life we accept variation in a hundred details, and we make use of the differences—in selecting our friends, our public officers or our favorite artists and authors. But how much variation can we accept in others? or in ourselves? How do we measure degrees of variation? What could we use as a standard?

The Average and the Normal We ordinarily judge other people by ourselves—by how far they agree with us in appearance, in behavior, in speech, in ideas. Yet hardly anybody is so pleased with himself as to suggest that *he* should be considered the standard. We commonly speak of the "average" as if that were a clearly understood standard. Almost anyone is "average" in most respects. Yet we would hardly take any individual at random as the standard by which to judge the rest of us.

We look for a standard by comparing large numbers of individuals. A

Margaret Bourke-White

INTERCHANGEABLE UNITS

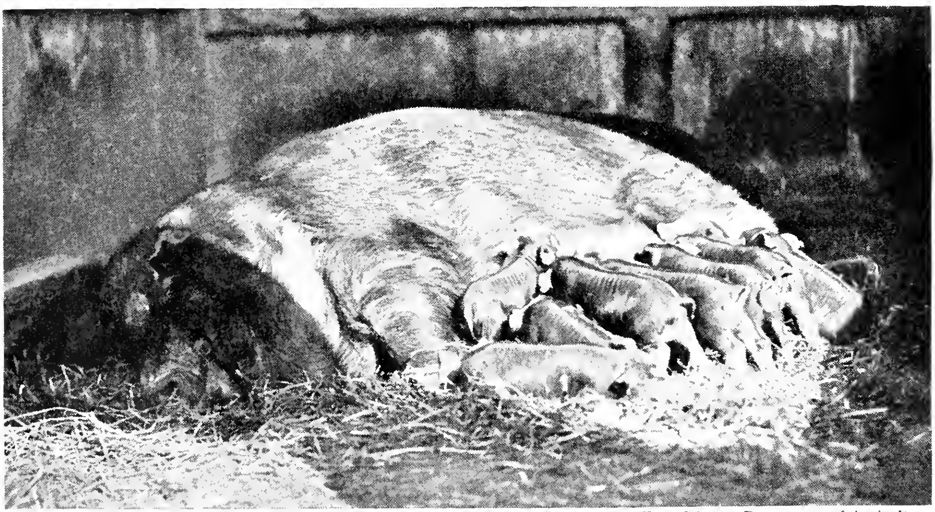
However different these men and women appear, any one will do as a "medical student at the University of Tiflis" in Transcaucasia

common way of setting up norms (from a Latin word, *norma*, meaning "a rule") is by getting the "average" of a large number of measurements or counts. This number is obtained by adding all the measurements and then dividing the sum by the number of individuals measured. The average is a useful basis for comparison: you can say, for example, that Marion is taller or shorter than the average.

The average, however, is not necessarily an absolute standard. We see this when we consider characteristics that we can *count*. Thus, if we took the *average* number of eyes in a population, we should find it to be about 1.995; yet the *normal* number of eyes is 2.0.

When we are first impressed with the fact of "variation" we are likely to assume that it is haphazard, that each individual may be "different" in almost any way at all. But about a hundred years ago (1845) a Belgian mathematician, after measuring and recording the dimensions of thousands of people, came to the conclusion that there is a certain regularity, or orderliness, in these variations. Lambert Adolphe Quételet (1796–1874) showed that variation in stature, for example, could be represented by means of a simple mathematical formula (see illustration on page 69). This idea is pictured also in the diagram about the line of boys of the same height (see page 63).

Normal Variation[1] No matter what we measure about human beings, we find the same regularity. And we observe the same regularity if we measure any characters of plants and animals—number of stamens in roses, for example, yield of milk in cows, and so on. Every group of living things consists of individuals that differ from each other: each one is "irregular" or unique in his own way: *Yet there is a regularity in their variations.*

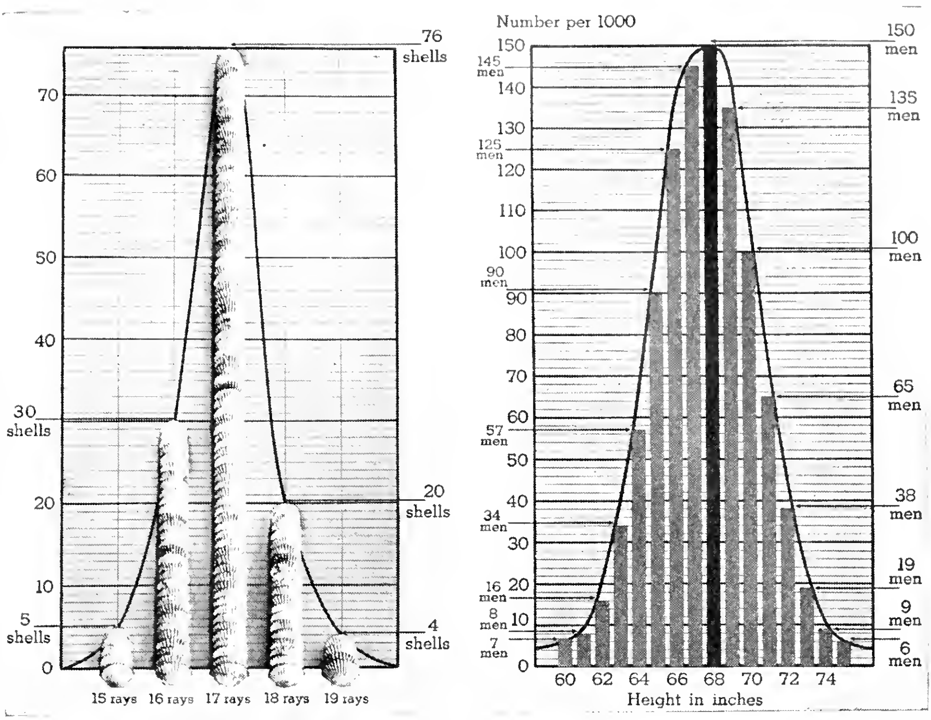


United States Department of Agriculture

AVERAGES ARE NOT ALWAYS MEANINGFUL

It is true that the average weight of the pigs in this picture is 41.6 pounds. But that tells us nothing that is characteristic of the group or of any individual. The "average" figure gives no hint of the fact that the 350-pound mother weighs about 14 times as much as all the little pigs together—each weighing about 3 pounds

[1]See No. 3, p. 75.



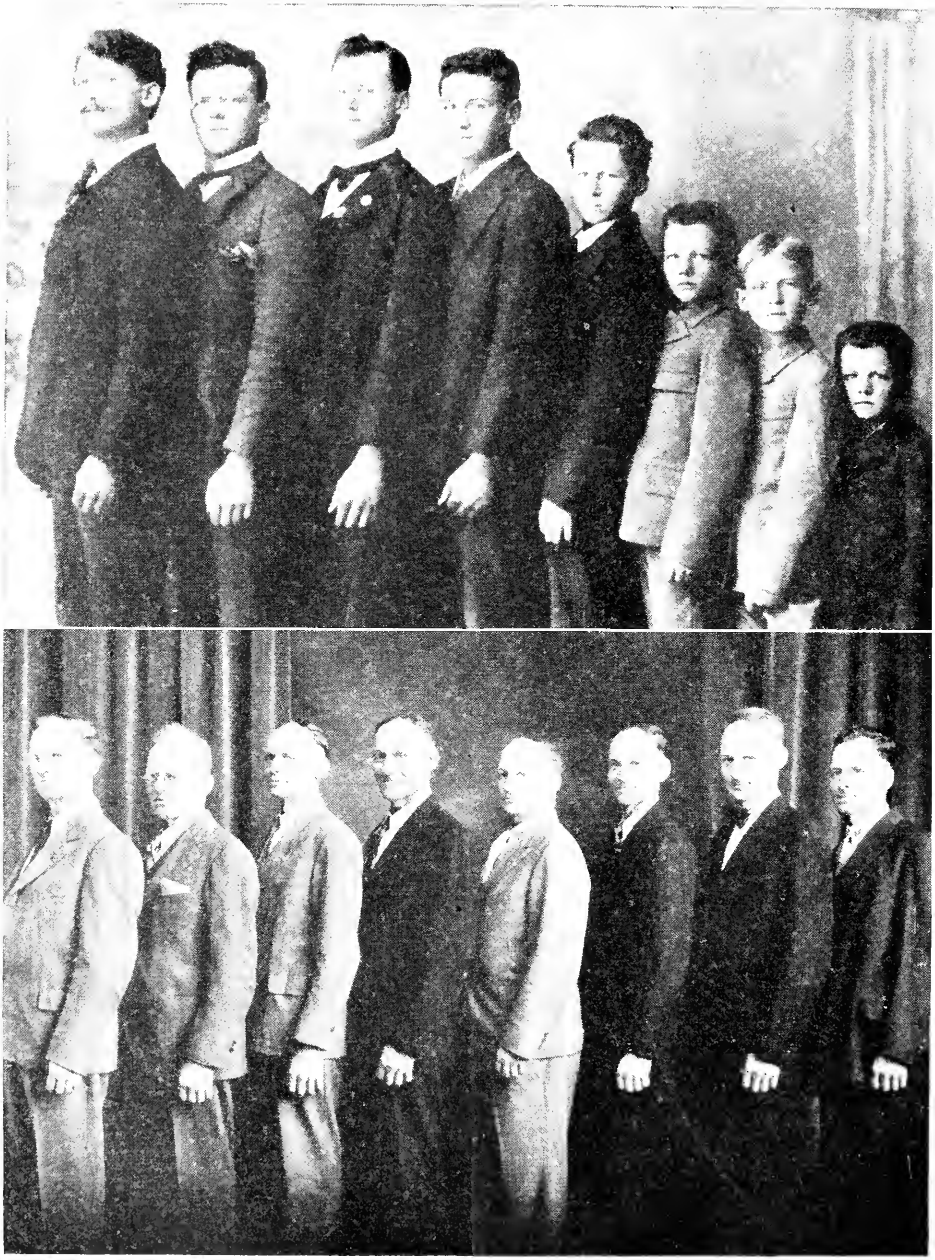
American Museum of Natural History

THE NORMAL DISTRIBUTION OF VARIATIONS

In any large sample of natural objects the variations fall into a regular pattern. More than half the men in our army are within two inches of the "average height". Only about a tenth are three inches taller than the average, and about the same number are three inches shorter. The number in each stature-group declines as we assemble groups of taller and taller or shorter and shorter men. If we arrange scallops according to the number of ridges, or rays, or if we arrange earthworms according to the number of rings, we find similar "curves of distribution"

This fact of regularity furnishes a basis for a new kind of norm. It is not enough to say that one is thicker or thinner than the "average". We want to know how much thicker or thinner, or *in what part of the range* of variation a particular individual stands, or how near to one or the other extreme.

Human beings probably differ from one another in more ways than the individuals of any other species. At the same time, each of us is sensitive about being "different". Many of us feel a constant struggle between the desire to be distinctive, to stand out on our own, and the fear of being different. This is because our population is itself a mixture of many races and groups that are but slowly learning to live with strangers. The most uniform objects of the same kind are the products of modern machinery—like



Simon M. Schwartz

AVERAGES AND DIFFERENCES

The eight Jones boys stood in a row for a family photograph in 1898, and again in the same order in 1940. The average height or weight means nothing for the boys in the first picture. Although no two are exactly alike on the second exposure, not one is very far from the average

screws or milk bottles. We have to accept the fact that for human beings variation is itself normal.

When Are Individual Differences Important?

The Individual and His Individuality Human beings are not satisfied to exist merely as separate individuals, like the separate ants in an anthill. Each of us wants to be recognized as a distinct *person*, with his own name, and never mistaken for anybody else. Each of us wants a chance to live as a unique person, to be his own *self*. It is no doubt true that one's distinctiveness comes out of the particular combination of his many traits. It is true that we sometimes wish that we had a little more of this or a little less of that. But in the end we feel that the selfness is the important thing.

We get definite information about every detail by comparing, weighing and measuring. But since we most frequently use numbers in trade and finance, many of us come to think that *more or less* of anything must also mean *better or worse*, or of greater or less worth. We are influenced also by the fact that in many of our everyday activities and relationships quantity is of great importance—running faster, for example, or lifting a greater weight. Yet the distinctive quality is probably the "whole self". The variations in detail have to be accepted—both in ourselves and in others—as perfectly "normal", or typical, for the species. Variation is not a technical term with some mysterious meaning, but a direct description of a general fact that we can observe all around us.

Equality and Individuality In our kind of democracy we hear a great deal about "equality". This term suggests something that we feel is important. Yet it often confuses us, for we know that actually we are unequal: we differ in regard to every trait that we take the trouble to measure. On the other hand, being different does not necessarily make one "better" or "worse". The best mathematician may be poor in languages. The best orator may be afraid of the dark. The great musician may be color-blind. The great financier may be a poor companion at home or among friends.

We consider each human being important for himself, not for any special talent or virtue he may have. We consider it necessary that each person have the opportunity to live the kind of life that is most satisfying to himself. This means, of course, that all others must have equal opportunity. It is in this sense, then, that we are all equal. However much we differ physically and intellectually, we are equal as members of the family or of the nation; we are equal as persons or as members of a religious group.

If we were all actually equal in every way, the question of equal opportunity or of democracy would have no meaning at all. Equality of opportunity, in the sense required by democracy, is important precisely because

we are *not* identical in our needs. And it means not that we all have a chance to do exactly the same things in the same way, but that we have equal chances to be different—for one person to be a vegetarian, if he likes, and for another to eat meat.

Since human beings normally live with others, each one must make some concession to those others in various ways. We have to observe the rules of the road and the traffic signals. We have to hold back at mealtime, even if hungry, out of consideration for the group. We have to accept "regimentation" as to the exact time for catching trains or boats or for listening to a radio broadcast. This is the price we have to pay for the satisfactions we get from living with other individualities.

In every kind of civilization the individual is tolerated if he conforms to the rule. Making the most of himself depends upon the kind of civilization in which he lives, on what kinds of freedom and what kinds of "equality" there are. We value *democracy* because it is a kind of relationship in which the individual can speak up to suggest changes in customs and in laws or in architecture and education. Such freedom is "equal" for all: it rests on the regard we feel for one another rather than on the privileges of power or standing. For the "right" to speak up and criticize and suggest improvements obliges each one to consider what the others have to say.

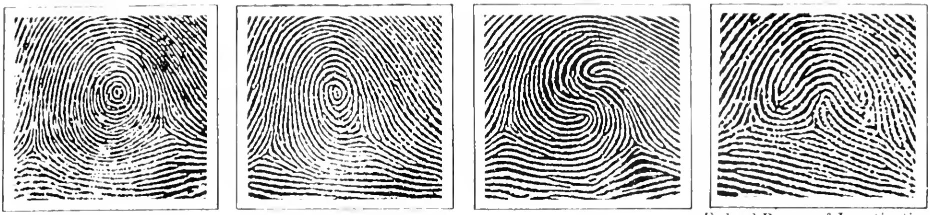
In such a civilization, invention and initiative by countless individuals constantly adjust what we have to what we want or need. It is not necessary to wait for a great genius or a dictator or a "revolution" to make a fresh start after conditions have become intolerable. Those who consider individuality important must ask about their civilization, What are the rules? Who makes the rules? How can they be revised? What are they supposed to accomplish? How many of us thrive under these rules, how many of us suffer?

Is There Individuality among Other Living Things? ·

No Two Alike Each of us knows scores of persons apart, even if we do not know all by name. A shepherd looking after 150 or 200 sheep is usually able to know each one, and he can tell immediately that some particular one is missing. His charges may behave like sheep, but each has about him something distinctive.

Among several peas taken out of the same pod, we can easily find differences in shape or in the coloring or in the wrinkles of the skin. If we weigh or measure each pea in a pint of peas, we find differences. If we arrange them according to size, we find nearly half close to the average size, very few of the largest, very few of the smallest, and the rest distributed regularly on both sides of the middle measure (see illustration, p. 69).

Plain arch — Tented arch — Loop — Loop



Federal Bureau of Investigation

Plain whorl — Central pocket loop — Double loop — Accidental

FINGERPRINTS AS DISTINCTIVE AS FACES

Details so small as ordinarily to escape notice show such variations that they serve as a most dependable means of identifying particular individuals—whether they are criminals wanted by the police or kidnaped businessmen wanted by their families

Two fish may be of exactly the same size, or two leaves on a tree of the same length, just as a hundred girls may all weigh exactly ninety-nine pounds. Yet each is unique. For however much alike they may be in two or three or ten characteristics, they still differ in vastly more details. We are able to distinguish one from the others, in spite of many resemblances.

The fine skin ridges on the tips of our thumbs and fingers are so distinct that they are generally used for reliable identification of individuals (see illustration above). We do not, of course, recognize our friends by these unique marks, nor do we take any special pride in our own unique patterns. That is to say, being unique is not necessarily a source either of satisfaction or of chagrin: in many respects it just doesn't matter.

Every living thing is thus a unique combination of particular characters or qualities. Among human beings, however, the individual is conscious of himself as a person. We consider the uniqueness of the human individual important, whereas we do not consider the uniqueness to be important to the individual oyster or fly, for example. The unique combination might be—and actually is—altered without affecting what we value in personality or individuality.

In Brief

Each individual differs from other members of his group in physical characteristics, in chemical make-up, and in many organic capacities.

Each person builds up his own picture of what is normal, or standard, with respect to the numerous details of life.

A common way of finding norms for groups is to determine the average for each of several sets of measurements.

The individuality of any living thing lies in its *unique combination* of many varying factors.

Although each individual is unique, several unique things resemble each other sufficiently to let us deal with them as of the "same" species or kind.

Each person apparently wishes to be like others of his group, yet distinct enough to be recognized as an individual.

Standardized ways of doing things under different circumstances represent the price we pay for the satisfactions and benefits we derive from living with others.

EXPLORATIONS AND PROJECTS

1 To find the variations among the individuals of a group, note the ways in which the various members of the class differ from one another. List the kinds of variations found. Do the same for the individuals in a litter of mammals, or a brood of chicks, or the leaves from a given tree, or some other group of "the same kind".

2 To find the extent to which the members of a group vary in stature:

Line members up in order of height and note (*a*) the region in which there are the greatest numbers having almost the same height; (*b*) the relative numbers of very tall, of very short, and of medium height.

To find the middle height, or *median height*, of the group, count from either end, to locate the middle person. The *height* of this person (or the average height of the two at the middle, if the group happens to be even-numbered) is the *median*. This measurement is also called the *50-percentile*, as half the group are taller and half are shorter. By counting individuals either way from the median, pick out the persons whose heights may be considered 25-percentile and the 75-percentile. Those taller than the 75-percentile are considered in the upper quartile, and those shorter than the 25-percentile are considered in the lower quartile, so far as height is concerned. Compare the *median* with the calculated *average* for the group.

To find the *range* of variation, determine the difference between the shortest and tallest members, or the total variation in height of the class. Find how the range of the lower half compares with that of the upper half. Find how the range of each of the four quarters compares with that of the others.

3 To make a graphic representation on the blackboard of the "frequency distribution" of the statures for the members of a group, enter a bar or stroke for each individual corresponding to his height-class. Plot along the horizontal base line spaces about 3 inches wide, say, for each inch of height (60–61, 61–62, etc.). For each person having each specified height, mark off an inch space above the base line.

In each column the spaces marked off correspond to numbers of individuals. The diagram shows that there are more of one stature than of another. It enables us to determine at a glance (*a*) what statures are most frequent or least frequent; (*b*) the median height; (*c*) the proportion of individuals having nearly median height; (*d*) the extreme range of statures in the group; (*e*) what the distribution is among the four quarters.

QUESTIONS

1 In what ways do individuals of your acquaintance resemble one another? differ from one another?

2 How can we measure the differences or resemblances among individuals?

3 In what ways are differences important to us personally?

4 How do we get our ideas as to what is normal for people?

5 Wherein does the individuality of a particular person consist?

6 What are the sources of the differences among individuals?

7 In what kinds of society have the individuals who differ widely from the norm greatest opportunity to use these differences to the full? In what kinds of society have such individuals least opportunity?

8 In what ways is it an advantage to a group to have people differ from one another? a disadvantage?

9 What evidence would be necessary to prove that some other race is superior to our own?

10 What evidence would you consider sufficient to prove that our race is superior to some other?

Since plants and animals come so close to our lives in a variety of ways, it is necessary for us to know the different kinds apart, especially to know which are beneficial and which are destructive. We have to understand how they act and how we can turn them to our purposes. But children and primitive people everywhere always interpret what plants and animals do —as they interpret other natural happenings—as if the objects were influenced by human likes and dislikes, or as if the objects were caused to act by outside beings like ourselves. They attribute to plants and animals—and nonliving things—the kinds of feelings which we human beings experience, such as fear, hunger, affection, anger, jealousy. Health and sickness, harvest and blight, sunrise and thunder, drought and flood, they explain as the work of spirits. These invisible fairies and imps push and pull things about; they get into and out of natural objects. They act just as we do, and for the same kinds of reasons.

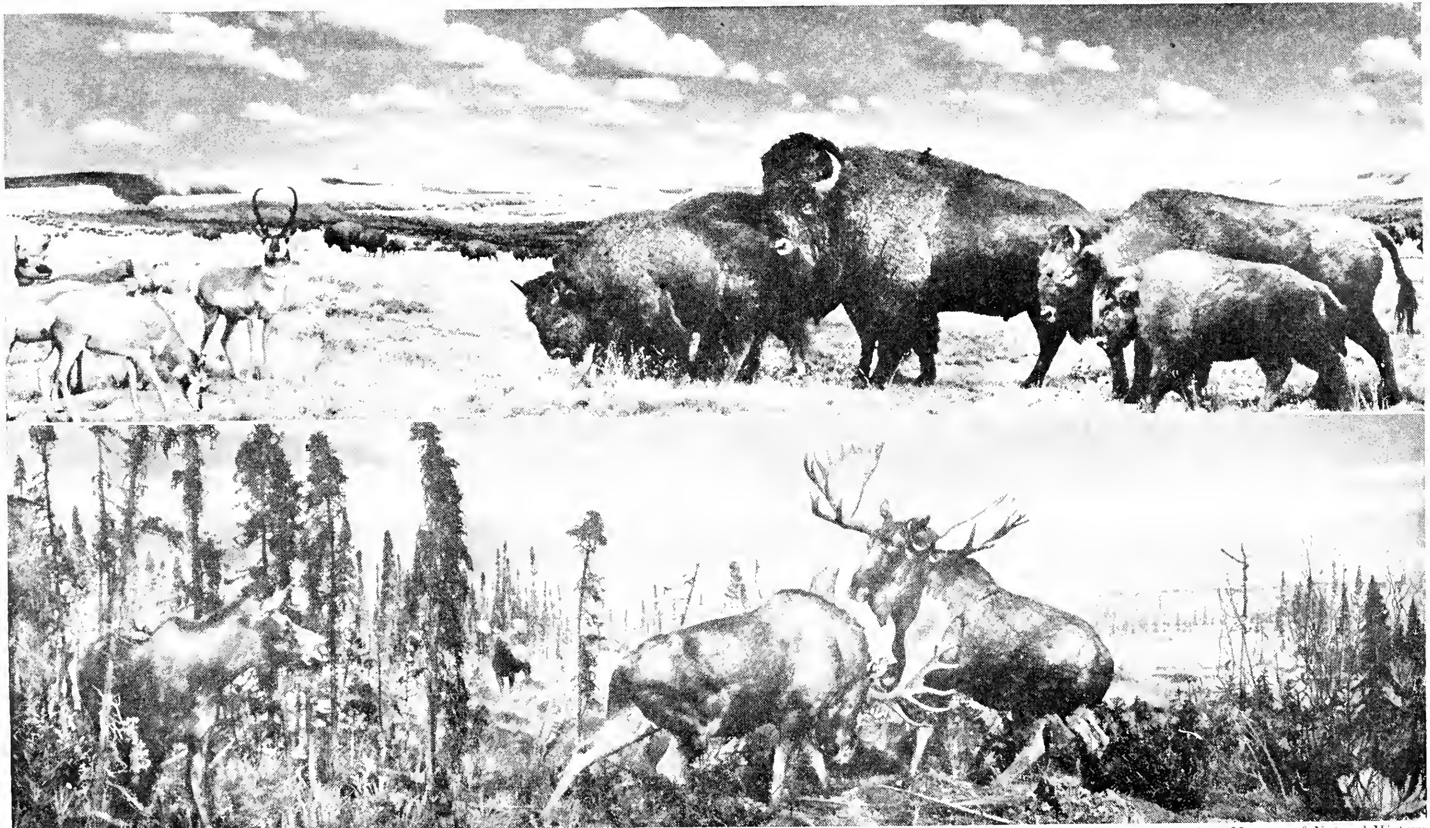
Now it is natural and reasonable for us not only to interpret whatever goes on in relation to our own interests, but also to judge events according to ourselves. For we have no way of judging—at least at first—except by our own doings and feelings. But while that kind of explaining is easy, and for a time satisfactory, it leaves us in doubt; it leaves us worried and anxious. This is because those spirits cannot be relied upon; they are capricious. If all goes well, it is comfortable to feel that the friendly spirits are in control. But if things go wrong—as they often do—we are not sure how we can manage the unfriendly spirits. Men have long been searching for understandings and interpretations of life that would enable us to make things happen our way with greater certainty.

People have improved their understanding by enlarging their horizons. The more plants and animals we are able to observe and compare, the broader is our outlook. Comparing many kinds from different regions enables us to sort them more satisfactorily and to communicate with one another about them on a world-wide scale. Such comparing reveals what plants and animals have in common with us, but also what distinguishes them from us. We learn that living things, including ourselves, have much in common with nonliving things; and that enables us to examine our problems with less emotion and with clearer vision. We try to find out what actually makes one cow yield more milk than another without blaming the difference upon the beliefs of the owners or upon the day of the week on which the cow or owners were born.

We discover many objects that are very different from us and yet certainly "living". We discover in all living things a slimy protoplasm that

uses food and grows and that responds to external changes in adaptive ways. We discover that plants and animals undergo regular changes, sometimes reproduce themselves, and unless in the meantime destroyed, complete a pattern of activities, or die. The combination of characteristics which distinguishes the living from the nonliving joins us human beings to the grass of the field and the birds and the beasts and the very fleas that infest the world. But beyond all that he shares with animals and plants, man has a hand and a mind with which he can reconstruct his world and make his dreams come true.

Finally, we think of ourselves as unique individuals, recognizing that being "different" is inseparable from being "alive". And so we come to accept ourselves and all others as equal—but different—members of that unique human species, just people, able to share in the great adventure of raising ourselves more and more above the beast.



American Museum of Natural History

WATER AND LIFE

In the wet Kenai Peninsula of Alaska, moose live on the tender swamp flora, among the shallow-rooted tamaracks. On the relatively dry prairie, drought-resistant grasses become the prominent flora and rugged grazing animals the dominant fauna

UNIT TWO

Under What Conditions Can We Live?

1 Why are there more plants and animals in some places than in others?
2 Why are there living things in some places but not in others?
3 Are there parts of the earth where there are no living things at all?
4 Are there any conditions in which man cannot live?
5 What limits the spread of mankind over the earth?
6 How do plants and animals remain alive while inactive during the winter?
7 Why are seeds killed if they are allowed to become damp?
8 Why do not fish drown in water? Why can they not live in air?
9 Why can we live longer without food or water than without air?

Man has spread over more of the earth's surface than any other of all the million or so species living today. He has taken with him in his wanderings some of his domesticated plants and animals, and also the fleas and worms and bacteria that live on or in his body. Man has made himself at home where the tiger or the bison had been master. In every region he has turned to his use the native plants and animals. And he has destroyed many species that he could not use, or that interfered with his plans. He wipes out a forest to make room for homes and gardens and field crops. Or he pushes snakes and wildcats aside to make room for cattle and chickens and dogs.

Man is not, of course, the only wanderer. Living forms everywhere push out into the surrounding regions. At the edge of a garden are weeds, and beyond the weeds are cultivated plants "escaped" from the garden. After a piece of land has been cleared, seedlings from the surrounding woods appear. The range of every animal species changes in the same way. Most of the flies that trouble us, and the vermin too, breed, of course, on the neighbors' premises. The locust swarms over the land, seeking what he may devour.

Life is always on the move. But in any given situation, or with any given species, life moves so far, but then meets many kinds of obstacles. The edge of the ocean stops the spread of life in both directions. The very conditions that enable some species to live make life quite impossible for others.

Fishes live only in water; the trap-door spider and the horned toad only in arid regions. Butterflies flit in the air and sunshine, but tapeworms dwell in the dark recesses of a little boy's intestines. The green-slime thrives on the bark of a tree, but the malaria plasmodium must get inside a blood-cell. Lichens live under the snows of Iceland, but Florida winters are too severe for the banana. Life is truly wonderful, since it gets along under all these different conditions. *Yet no single kind of plant or animal can live under all these different conditions.* What conditions are really essential to life?

CHAPTER 5 · WHAT HAVE WATER AND AIR TO DO WITH BEING ALIVE?

1 Is water necessary for all living things?
2 How can there be any life in the desert?
3 Do lichens growing on rocks need water?
4 How long can we live without water?
5 How long can one go without breathing?
6 What has breathing to do with life?
7 Are all parts of the air necessary for life?
8 What makes dry seeds sprout?
9 What happens to the living things in a pond when the water freezes solid?
10 What happens to the life in a stream when all the water dries up?
11 How does the air we breathe out differ from the air we breathe in?

On a farm, the weather seems very important. Crops grow more luxuriantly where rains are frequent. Prolonged drought ruins them. Forest vegetation likewise depends upon rainfall (see illustration, p. 78). What makes things grow faster when water is plentiful? How does water act in plants?

The amount of water varies not only from region to region, but from season to season, in any one place. During winter there may be as little sign of life as in a desert: most plants and animals of the preceding season are dead. Of those plants that are not dead most are either bare of all foliage or reduced to some kind of resting state. Roots and stems are lying dormant—that is, sleeping—underground. Millions of seeds look as lifeless as pebbles. In general, similar facts may be observed regarding animals. The winter state is in some ways a *dry* state. Has water anything to do with the way seeds behave in winter, as compared to the way seeds behave in spring or summer? What is the connection between water and being alive?

How Does Water Act in Protoplasm?

Protoplasm a Chemical Machine Living machines differ from most of our artificial machines in depending directly on chemical changes going on within the protoplasm. The protoplasm itself is largely water—well over 90 per cent in many kinds of plant and animal cells. Of the various substances in the protoplasm in addition to water, some are in solution, like salt that has dissolved in water. Others are suspended in water, like the solid

part of mucilage or like fine particles in a muddy pond. These various substances are constantly undergoing chemical changes.

Chemical processes inside a plant or animal, like those in a test tube or a soap kettle, can take place only in a fluid state. In living things this fluidity is maintained by the large amount of water.

Unlike the test tube or kettle, however, the living cells of leaves and stems, of muscles and nerves, require a constant flow of water. For the water itself takes part in some of the chemical transformations of protoplasm, so that it is constantly being destroyed. In other cases the activities involve a loss of water through the walls or membranes of the cell. There is in fact a constant flow of water between a living cell and its surroundings—water coming in and water going out.

Sprouting of Seeds In the spring the gardener or the farmer places his seeds in the ground, and they sprout. Since our common cultivated plants normally grow in soil, we are likely to assume that the *soil* somehow starts the seeds to begin their active growth after their long rest. The soil is a mixture of many kinds of stuff, some of which may have something to do with the sprouting, but not the others.

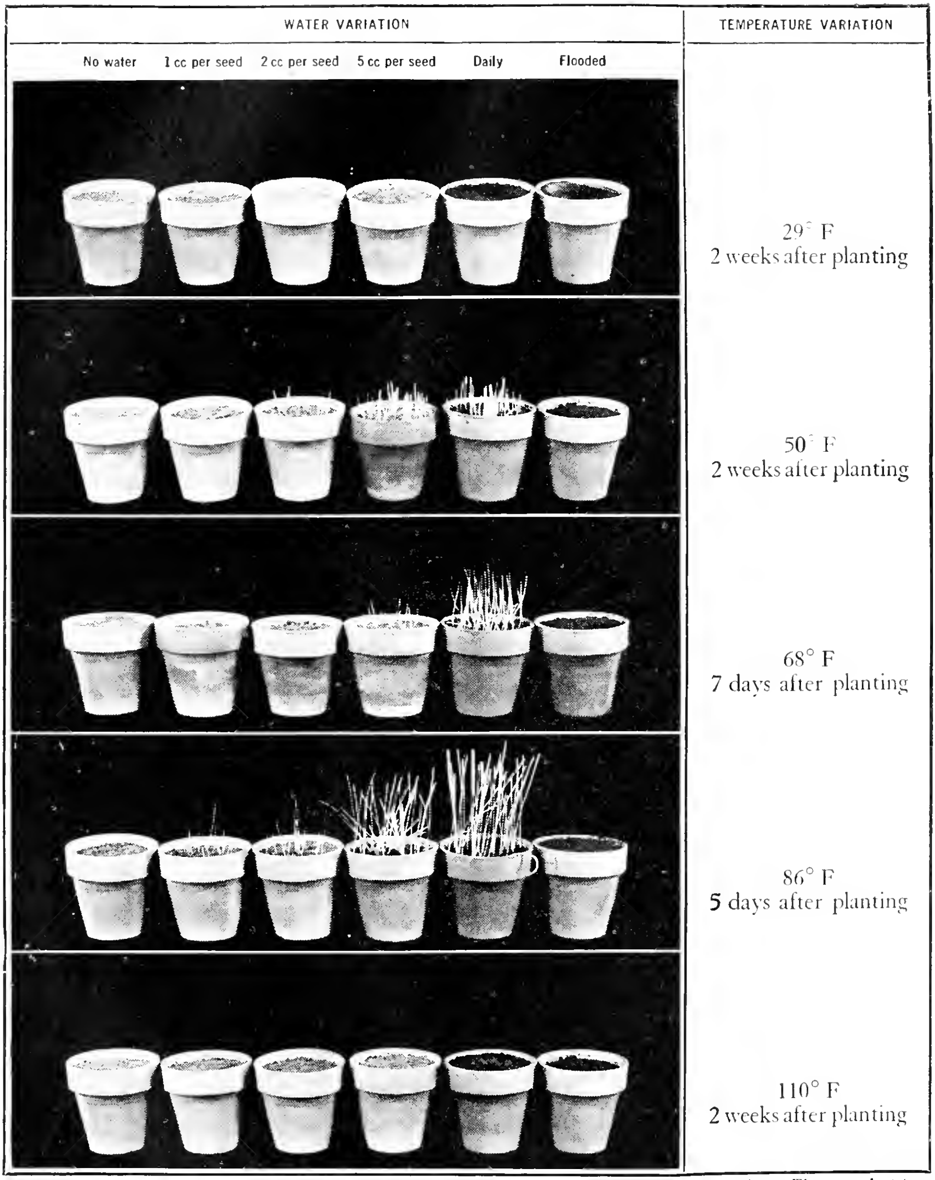
Most of us know that seeds kept in jars will not sprout, whether they are kept in the dark or exposed to light. Hence it is not on account of darkness that seeds germinate in the ground. Seeds kept in a warm place and seeds kept in a cool place will both fail to sprout so long as they remain in our jars or boxes. It cannot be temperature alone that makes them sprout in the ground. Perhaps the soil keeps some of the air away from the seeds? But keeping air out of the jar will not make the seeds sprout.

In regard to the chemical substances in the soil, our usual experience tells us nothing at all. If we place the seeds in boxes containing the various ingredients of the soil, such as sand, clay and various salts, we shall find that not one of the seeds sprouts.

This suggests that even if any of the substances might cause sprouting, none *can get into the seeds* in the dry state. We should therefore try these substances with water. But has water by itself any effect on the sprouting seeds?

An experiment in which some seeds are placed with various amounts of water, while other seeds from the same lot are kept under similar conditions of air, light and temperature—but without water—will easily convince us that a certain amount of water is a necessary condition for starting the germination of the seeds.

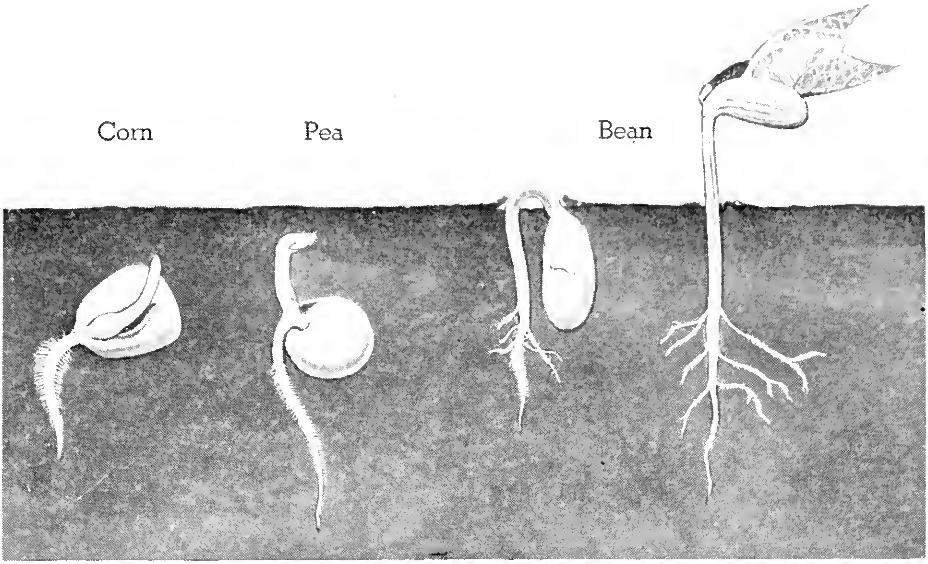
We shall find also that some kinds of seeds will fail to sprout if they are completely covered with water, although other kinds will sprout under those conditions. This suggests that water may have injured the seeds, or that they drowned because of lack of air.



L. P. Flory, Boyce Thompson Institute

GERMINATION INFLUENCED BY MORE THAN ONE FACTOR

Experiments in which equal numbers of seeds were exposed to different temperatures and to varying moisture showed that at a given temperature suitable for germination, there may be too little water or too much water; and that with a suitable amount of water, the temperature may be too low for the seeds to sprout, or it may be too high



CULTIVATION TO CONTROL GROWTH OF YOUNG PLANTS

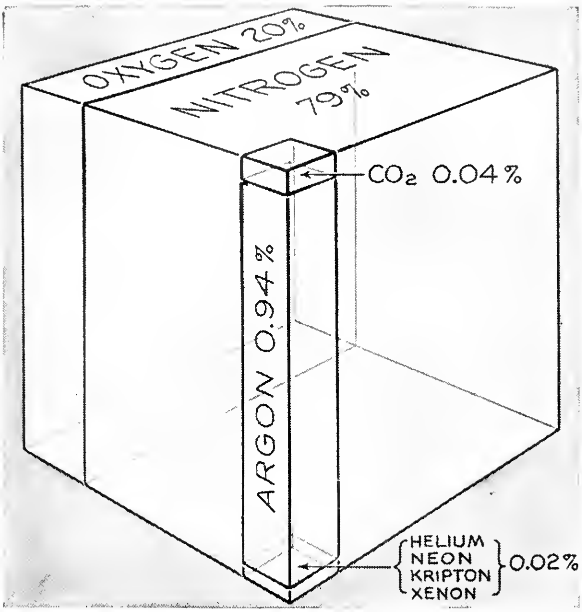
Hard rains sometimes pack the soil, limiting the air supply. Cultivation loosens and aerates the soil. It also limits the loss of water by evaporation. Cultivating beans at the time the "necks" are pulling the seed leaves above the ground may break off and kill many of the young plants

It may be that other factors also play a part after all. For example, in the presence of water seeds may sprout at one temperature but not at another. From actual experience we know that we may safely sow seeds of some species earlier in the spring than others. From experiments we learn also that some seeds will fail to sprout when it is too cold or too warm.

How Is Air Related to Life?

Air and Life The atmosphere has approximately the composition shown by the diagram in the illustration on page 84. When air is shut off, we suffocate, as in drowning. Now what is the connection between air and being alive?

The energy of protoplasm, in all its activities, comes from the burning, or *oxidation, of materials derived from food.* The food is not burned directly, like the oil in a furnace. It first undergoes many changes through which it is finally assimilated, or made into living protoplasm. Nor is the oxidation, or burning, like the familiar flame. It takes place only in the presence of water, whereas the fires with which we are familiar cannot burn under water.



The air consists of at least seven distinct gases. Nitrogen and oxygen together make up about 99 per cent of the total. Although the proportions of these gases are constantly changing, the turbulence of the air mixes them so thoroughly that samples taken in different places vary but little. In addition to these gases, the air contains varying portions of water and dust. So far as life is concerned, the most important parts of the air are oxygen, carbon dioxide, and water. Nitrogen is an essential part of all living matter, but very few organisms can get it directly from the atmosphere

COMPOSITION OF DRY AIR

The nearest thing to the oxidation of protoplasm that is familiar to most of us is the rusting, or oxidizing, of iron, which also takes place in water.

Air and Energy[1] We may compare the oxidation of food in living protoplasm with the burning of fuel. When we burn coal, which consists chiefly of the element carbon, oxygen of the air combines with the carbon, forming carbon dioxide and liberating heat:

$$\underset{\text{carbon}}{C} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{carbon dioxide}}{CO_2} \text{ (and heat)}$$

Wood is composed chiefly of cellulose, an insoluble material consisting of carbon, hydrogen and oxygen, in the same proportions as they are found in a simple sugar. When wood burns, heat is liberated, and water is given off, as well as carbon dioxide.

Familiar fires give off heat and light. Oxidation in protoplasm also results in heat and other forms of energy. When glucose, a kind of sugar, is oxidized in protoplasm, energy is liberated, and carbon dioxide and water pass off as waste substances:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2} \longrightarrow \underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water vapor}}{6\,H_2O} \text{ (and release of energy)}$$

In an engine the oxidation takes place in the firebox or in the cylinder. In a living plant or animal *oxidation takes place in every living cell.*

[1]See Nos. 1–5, pp. 93–94.

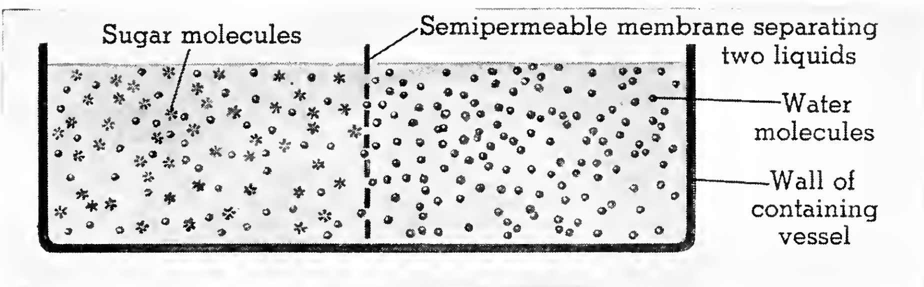
Among the forms of energy liberated by protoplasm are motion (as in muscles), heat, electricity, light, and the processes that are confined (so far as we know) to nerve and brain cells, such as thinking, wishing, suffering, enjoying. In glowworms and fireflies, as well as in certain bacteria, slow oxidation liberates much of the energy in a sugar as *light.*

Air as Raw Material Although carbon dioxide is but a fraction of 1 per cent of the atmosphere, it is a very important factor in the life of the world. For this fraction is a considerable part of the raw material out of which the green plants make sugars and starches (see pages 137–138). And these in turn are the beginnings of all foods, for us and other animals, as well as for the plants.

How Does Exchange of Materials Take Place between Living Cells and Their Surroundings?

Diffusion[1] If a bottle of perfume or ammonia is opened in a corner of a room, the odor will become perceptible in all parts of the room. Sugar left in the bottom of your coffee, without stirring, will in time spread throughout the liquid. Every portion of the now cold coffee will become equally sweet. The process by which a liquid or gas penetrates another liquid or gas is called *diffusion*, a "spreading apart".

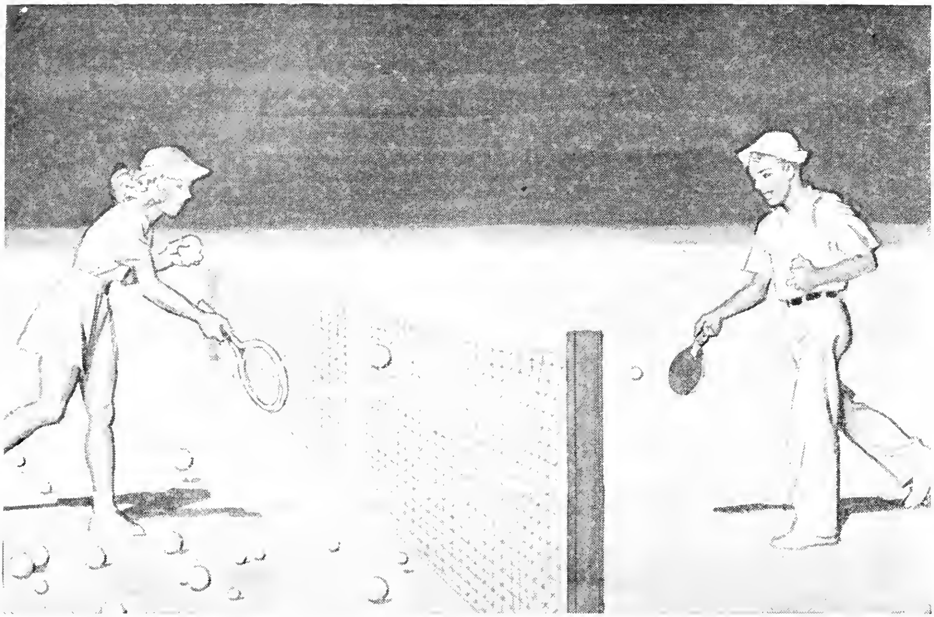
When salt or sugar gradually diffuses from the bottom of a vessel of water to all levels, "work" is going on. For material is being raised against gravity and distributed through space. It helps us to understand what hap-



DIFFUSION THROUGH A MEMBRANE

We may think of the molecules in any liquid or gas as in constant motion. Some molecules are smaller than others. In the diagram the sugar molecules are represented as too large to pass through the pores of the semipermeable membrane. Since more water molecules bombard a given area on the right side of the membrane than on the left side, more water moves toward the left side than in the reverse direction

[1]See No. 6, p. 94.



HOW DIFFUSION TAKES PLACE

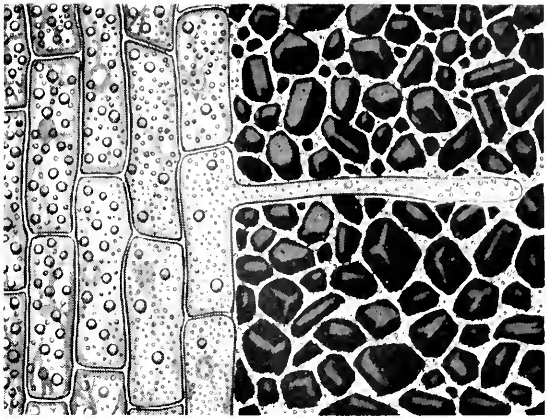
If we throw balls of different sizes at a tennis net, we may expect most of the smaller balls to go through the net, and all or most of the larger ones to be stopped. In much the same way, we imagine, some of the rapidly moving molecules of dissolved substances pass through the pores of an osmotic membrane, while larger molecules move through in smaller numbers or not at all

pens in roots and in other parts of living things if we think of this work as the action of the rapidly moving molecules. But there is still the problem of understanding how roots work, since they seem to be raising water against gravity, and they seem, at any rate, to be taking more out of the soil than they might be giving off.

The cell walls of the root, and of practically all plant parts, consist of cellulose, a substance that does not dissolve in water, but does absorb water in the same way as glue or gelatin. Now, we must imagine that wherever there is water, substances dissolved in it will diffuse in it. When the cellulose walls of root-hair cells are saturated with water, the molecules of dissolved substances diffuse through this water. This kind of "diffusion through a membrane" is called *osmosis*, from a Greek word meaning "to push". We conceive osmosis to be taking place through the walls of all cells, those of animals as well as those of plants.

Since the liquid or solution inside the root hair is different from the soil water surrounding the cell, we should expect that some of the substances would be diffusing into the cell, and other substances moving out of the cell.

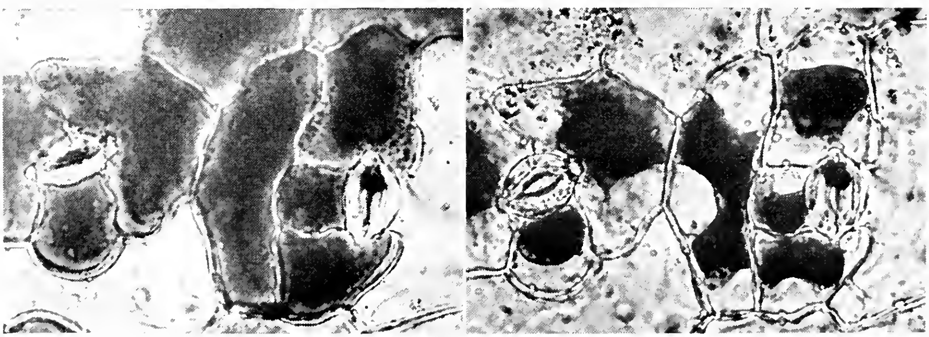
The root hair absorbs water from among the soil particles by osmosis through the cell membrane. In the cells near the surface of the root, the proportion of water molecules to other molecules is greater than in the deeper layers of cells, as we should expect. Water in the surface layers diffuses from cell to cell, passing through several cell membranes by osmosis. Surrounding a live root hair there is a constant flow of liquid



OSMOSIS IN ROOTS

Indeed, from what we know of the chemical activities of protoplasm, we should expect materials to be passing into cells and out of cells by osmosis, all the time. That is, there is a double current: (1) the protoplasm of a cell receives from the outside its supply of water, salts and food; and (2) materials of various kinds pass out of the cell. Gases as well as liquids diffuse through the wet cell wall. Every cell receives its income by osmosis, and it gets rid of its wastes by osmosis.

Osmosis in Living Things[1] Some substances dissolve in water more easily than others, and some solids do not dissolve at all. Substances in solution will diffuse, but not all will diffuse through a given membrane equally fast. And through some membranes certain substances will not diffuse at



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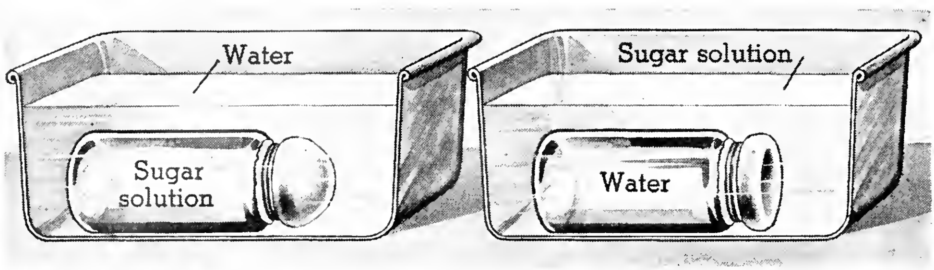
PLASMOLYSIS IN EPIDERMAL CELLS OF RED CABBAGE

When living plant or animal cells are placed in concentrated salt solution, the protoplasm shrinks from the walls of the cells as water diffuses out. An excess of fertilizer makes a plant lose water through the roots and wilt

[1]See No. 7, p. 95.



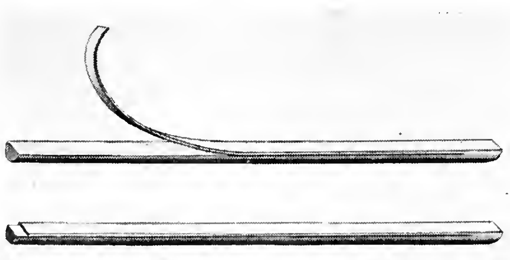
TURGOR AND OSMOSIS IN ARTIFICIAL CELLS

From the bulging of the membrane we infer that something passes through the membrane faster in one direction than in the other—increasing or decreasing the internal "pressure". In a living cell increased pressure results in a turgid, or swollen, condition, whereas reduced "pressure" results in a flaccid, or flabby, condition, as seen in wilted plants. By means of appropriate solutions and indicators we can demonstrate the passing of dissolved food materials and gases into and out of such "cells"

all. Cell walls and similar substances are therefore called "semipermeable". Osmosis appears to be selective. As a result of the difference in the behavior of dissolved substances, osmosis will be greater in one direction than in the opposite; and cells exposed to the same material surroundings may not be affected in the same way.

We can imitate the passage of materials into and out of cells by making model cells of small widemouthed glass bottles, each closed with a bladder membrane (see illustration above). By using appropriate solutions and indicators, we can demonstrate the movement of dissolved food materials and dissolved gases into and out of these "model cells".

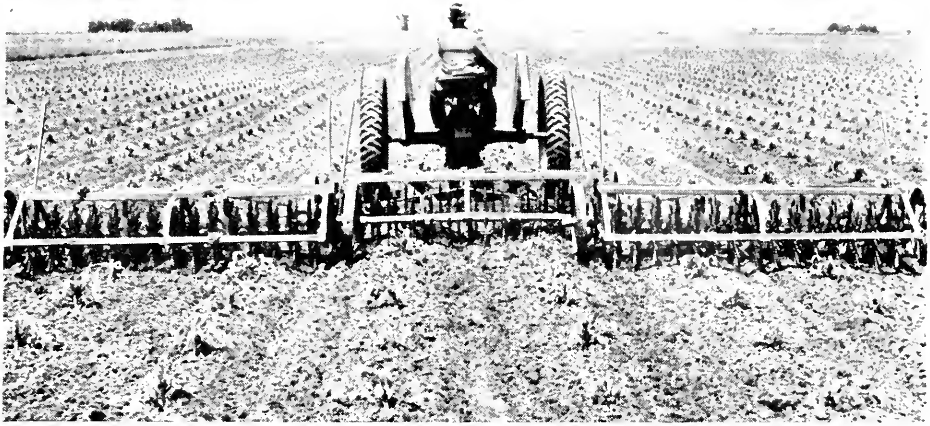
Osmosis and Turgor[1] When a cell has absorbed water so that the membrane is stretched, the cell is said to be *turgid*—that is, swollen. Turgid cells in the tissue of a plant or animal make the structure stiff, whereas wilted tissues are flabby—just as an empty meal sack is limp, whereas a full sack will stand on its own bottom. Similarly, turgid tissues crack through easily, as we see in the brittleness of celery or in the crispness of a juicy sausage. We



If we nearly split off a thin layer of a crisp rhubarb stalk and then place it back, it no longer reaches the full length. The shrinkage is due to the loss of water. The epidermal tissues are normally turgid, but when water evaporates from the cut surfaces each cell collapses somewhat

TURGIDITY AS SUPPORT

[1]See No. 8, p. 95.



United States Bureau of Plant Industry, Soils, and Agricultural Engineering

OSMOSIS AND TURGIDITY

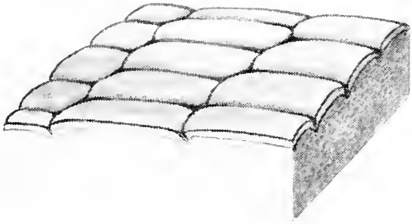
The gardener finds it easier to cut weeds with his hoe in the early morning, when the plants are turgid and brittle. Farmers plan to use the rotary hoe on young growing corn after the plants have wilted slightly, as otherwise the fingers of the hoe would break the plants

place the ends of celery stalks and of other leafy and root vegetables in cold water, and store them in a cool place, to keep them from wilting—that is, to retain their crispness.

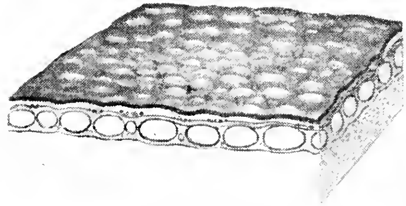
The turgidity of plant tissue holds stems and leaves up, even where there is little mechanical or fibrous tissue present. This is especially noticeable in the spring, when rather tender tissues push through the ground in their rapid growth. At the same time, these turgid stalks are easily broken, as every farmer and gardener knows (see illustration above).

How Do Living Things Adjust Themselves to Changes in Water Supply?

Adjustments The dryness or wetness of the environment varies in the course of the day, from day to day, from season to season, and from place to place. Marine organisms living along the shore experience alternate dryness and wetness with each change in the tide. Only plants and animals that live continually in deep water escape the seasonal variation in their environment. Land plants and animals that are exposed to drying conditions have, as a rule, coverings that prevent the rapid loss of water. Our own skin separates the marine-like interiors from dry and variable conditions outside.



Section of the skin
of a lizard



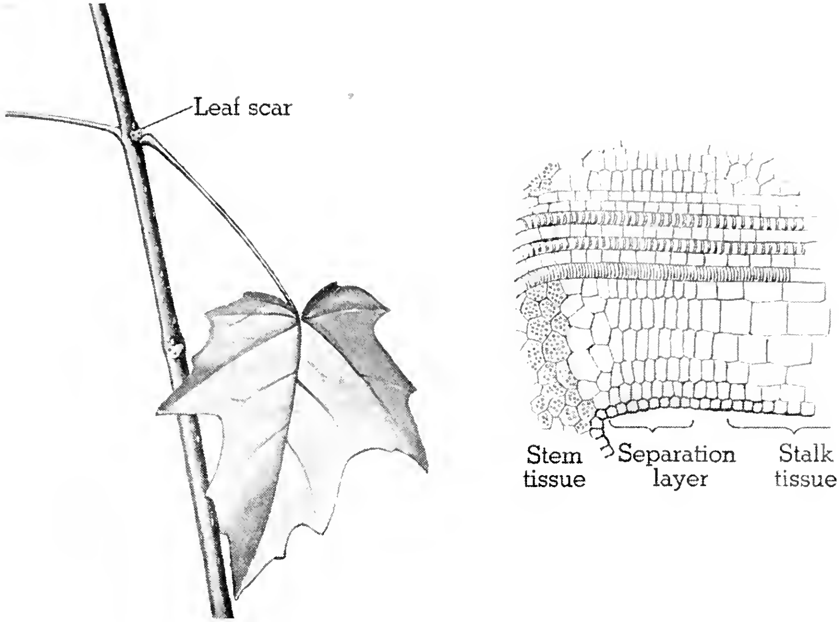
Section of the skin
of a salamander

MEMBRANES AND SCALES

The moist outer covering of a salamander is a living membrane which loses water readily. The dry scaly covering of a lizard is really dead tissue which is relatively impervious to water. We can see how quickly a frog loses water by balancing one on a scale in a warm, dry room for only a few minutes

BLOWOUT IN INDIANA DUNES

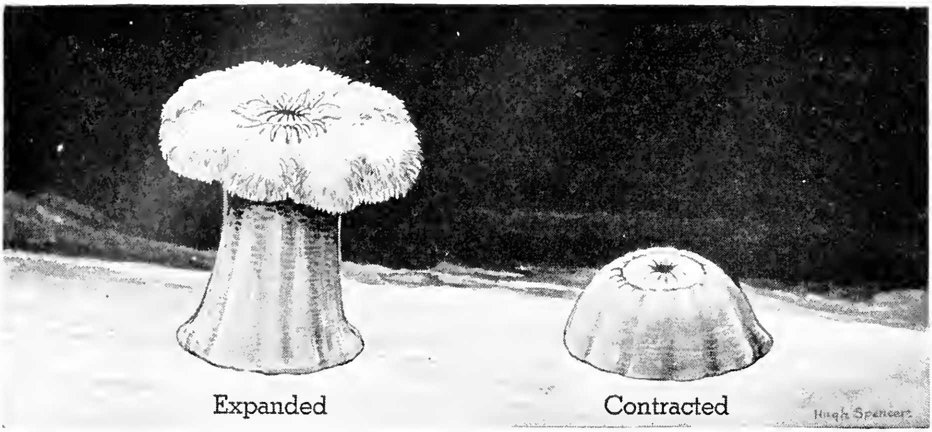
Most living things find the extreme heat and dryness of a blowout in the dunes intolerable. In brilliant sunshine the sand catches and reflects the light until a person walking through the blowout feels as if he were in a reflector oven. Dune grasses and some other species eventually get a foothold even in this desiccated environment



THE FALL OF A LEAF

Plants that regularly drop their leaves in the autumn form a special layer of cells in the stalk of each leaf, and sometimes of each leaflet of a compound leaf. These cork cells are thin-walled and turgid. Their contents break down into a mucilaginous mass, which dries up. A slight movement is now sufficient to break the fibrovascular bundle at this point, and as the leaf is removed the exposed surface becomes a self-healing scar

Organisms withstand heat and dryness very unequally. Man, for instance, dries out rather quickly in the hot, dry desert, although the evaporation from the skin and lungs lowers the body temperature and protects the protoplasm against becoming too hot. But the lost water has to be replaced, or the protoplasm will suffer other injury. During the Second World War many men who were saved from torpedoed ships, or from planes forced down on the ocean, later died for want of water. This was an urgent problem, and several lines of research were followed to solve it. Before any practicable means had been worked out for making sea water fit to drink, Gifford Pinchot (1865–) sought for fresh water in the life of the sea. Pinchot, who started the conservation movement, showed by experiments that the juice squeezed from the flesh of salt-water fish could serve men as drink in place of fresh water, as the raw flesh may serve as food. As a result of these experiments, airplane rafts and steamship lifeboats were equipped with fishing tackle and instructions for living on what the ocean yields.



CONTRACTION IN THE SEA ANEMONE

When disturbed, the animal greatly reduces its surface by repeatedly contracting until it resembles a wart on a rock

Seasonal Change As the autumn advances, the soil becomes drier as well as cooler. Fewer root hairs are now formed. The movement of water out of the leaves is reduced. Evaporation continues, however, so long as there is water in the cells. If the roots do not absorb enough to compensate for the loss of water, the live cells of the plant must suffer injury. The leaf cells are the first to be affected. The shedding of leaves seems to be related to the water factor, as well as to the temperature factor, which we usually associate with the change of seasons. This has been determined experimentally. The loss of the leaves prevents the complete drying up of the plant, and it also prevents the freezing of live cells (see illustration, p. 91). We may properly think of the fall of leaves as adaptive.

Life in a Tide Pool Organisms living along the seashore withstand drying when exposed to air and beating by waves when submerged. The seaweeds are tough and gelatinous, and often ribbonlike, offering little resistance to the water currents. Sea anemones, although consisting largely of water, have a firm outer membrane. Many of the animals secrete hard shells. These protect the soft bodies against the rushing water, enemies and drying. The mussels and barnacles close their shells while the tide is out. Clams draw in their siphons, sea anemones draw in their waving tentacles, snails close their horny trap doors, tube worms cover their burrows, and crabs move with the water or remain in pools left by the receding tide. All these water animals of this most exciting of environments lie low until the next tide surrounds them with water, permitting them to resume their search for food (see illustration, p. 579).

In Brief

Water, air, and a suitable temperature are essential conditions for the germination of seeds.

The chemical changes that are continuously going on in living protoplasm can take place only when it is in a fluid state.

The energy of protoplasm is derived from the oxidation of food materials within living cells.

Using oxygen and liberating heat are characteristic of nearly all living things.

Living cells continually exchange materials with the fluid medium which surrounds them, by osmosis, or the diffusion of fluid substances through a membrane.

In larger organisms dissolved substances reach the living cells through the medium of water.

Water filling the cells and tissues of plants stretches the outer membranes and furnishes mechanical support.

Organisms exposed to drying conditions often have protective coverings which prevent desiccation.

The shedding of leaves may be considered an adjustment to seasonal variation in water supply.

Living things show many adaptations to the extreme variations in the moisture, light and heat of their environment.

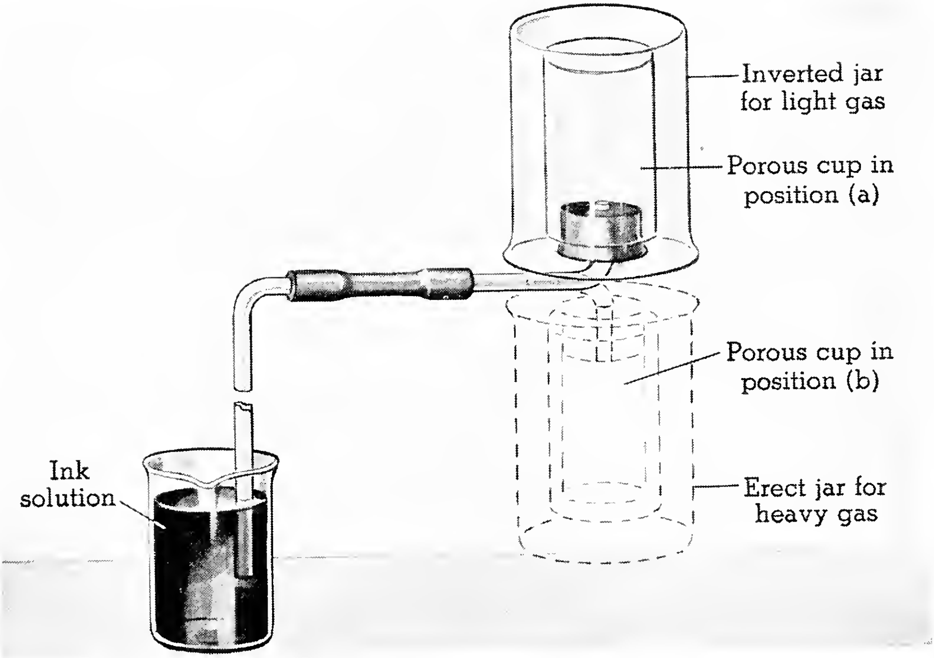
EXPLORATIONS AND PROJECTS

1 To find whether carbon dioxide is discharged when ordinary fuel burns, collect gases, given off by the flame of a lighted match or a candle, by holding over the flame an inverted clean and dry widemouthed bottle. Test the contents of the bottle for carbon dioxide and also the air in a similar bottle that has not been held over a flame.[1] Compare the reactions in the two cases and draw conclusions.

Incidentally, this procedure has also furnished information on the liberation of water during oxidation; for, starting with a dry vessel, we could see moisture condensed inside the bottle held above the flame. This can be checked by holding a similar bottle over a match or candle, not lighted, under the same conditions.

2 To see in what ways the oxidation of ordinary food substances is like that of common fuel, heat some sugar, starch, bread, butter, olive oil, lard, or other food material in an evaporating dish until it bursts into flame; remove the burner. In each case, ascertain whether water and carbon dioxide are discharged. In what

[1]A common test for carbon dioxide is a solution of slaked lime, "limewater", which turns milky when carbon dioxide comes in contact with it. In this experiment pour a little limewater into the jar and shake up to mix with the air.



ways is oxidation of food substances like the oxidation of ordinary fuel? In what ways is oxidation of food substances different from oxidation of ordinary fuel?

3 To show that slow oxidation liberates heat, place a tablespoon of dry potassium permanganate on a folded paper towel in a shallow pan above sand or asbestos. To a crater in the top of the permanganate add a teaspoon of glycerin. Cover with another folded paper towel (to prevent too rapid loss of heat). Rest pan on asbestos pad. Leave undisturbed until there is no doubt as to whether (*a*) heat is given off, or (*b*) oxidation is taking place. Record results and conclusion.

4 To find whether germinating seeds give out carbon dioxide, place about two tablespoons of soaked seeds in a sealed flask. Let stand overnight in a warm place. On the following day replace the solid stopper with a two-hole stopper carrying a thistle tube and a bent glass tube leading to a test tube containing limewater. Pass the gas from the flask through limewater by pouring water into the thistle tube. Bubble the air from a similar flask containing dry seeds through another test tube of limewater. Compare results and note conclusions.

5 To find out whether the air we exhale contains more carbon dioxide than the air we inhale (that in the room), inhale and exhale through two separate bottles of limewater several times. Compare results and note conclusions.

6 To demonstrate the diffusion of gases, set up an apparatus as in the diagram. Fill an inverted quart jar with a light gas, such as hydrogen or illuminating gas, and place it over the porous cup in the position (*a*). Similarly, fill an upright jar with carbon dioxide and place it around the porous cup as shown in position (*b*). Compare what happens in the ink-solution indicator as you test different gases, and account for the results.

7 To demonstrate osmosis: Temporarily seal the small end of a thistle tube and fill the bulb with granulated sugar. Pour as much ink or colored water as possible on the sugar in the bulb. Tie a moist bladder or sausage-casing membrane firmly in place over the large end with about twenty turns of thread. Invert the thistle tube, attach a long glass tube to the open end with a piece of rubber tubing, and place bulb in a jar of water.

Hollow out the thick end of a large carrot (use apple-corer if convenient) and partially fill the space with sugar and ink; seal a glass tube in the open end of the carrot with a one-hole rubber stopper. Keep top of carrot dry during this sealing process. The outside may be reinforced by wrapping with friction tape; the top may be sealed with candle wax or paraffin. Submerge the carrot in a jar of water.

Record results in both cases and account for them.

8 To show how water can furnish mechanical support by filling the cells and tissue and stretching the outer membranes:

Prepare two widemouthed bottles to represent cells, as shown in illustration on page 88; fill one with a concentrated salt or sugar solution and the other with pure water; tie an "osmotic" membrane securely over the top of each; submerge the one containing the sugar or salt in a pan of water and the other in a pan of water containing salt or sugar solution. Compare the behavior of the two membranes and show wherein one of the model cells represents the condition found in the cells of wilted celery, the other in fresh celery.

Cut fresh rhubarb stalks squarely at one end; then peel down a narrow strip nearly the full length from the cut end; place the peeled portion back along the cut surface and note that the two no longer match. Split dandelion stems lengthwise; note how they curl. Place some of the split stems in fresh water and others in salt water. Record results in each case and explain how they came about.

Cut four thin slices each of carrot, turnip and potato. Place one slice of each in fresh water, one in a salt solution, one in a saturated sugar solution, and one in air. The following day note the differences among the slices and account for them.

Water one pot of rapidly growing seedlings (corn, oats, or wheat) with a saturated salt solution and another with tap water. After a few days compare the behavior of the plants in the two pots and account for the differences.

QUESTIONS

1 What conditions are essential for the germination of seeds?

2 In what respects are the chemical processes which go on inside a living organism like those which take place outside? In what respects are they different?

3 How is the energy of protoplasm derived?

4 What kinds of energy are released by protoplasm?

5 In what respects is osmosis like the passing of water through a sieve? In what respects is it different?

6 What relation is there between temperature and the rate of diffusion?

7 What conditions will produce turgidity in living tissues?

8 In what ways do living things adjust themselves to changes in water supply? What conditions produce the most severe changes in water supply?

1 Must all living things have food?
2 Do all animals have mouths?
3 How do plants get food?
4 How is it that some animals eat animals and others eat plants?
5 Do any plants eat animals?
6 Is the food of one organism suitable for other organisms?
7 Can we change the nature of an animal by feeding it different foods?
8 What do hibernating animals use for food?
9 Do all people have to use the same foods?
10 What do different kinds of food do for a living thing?

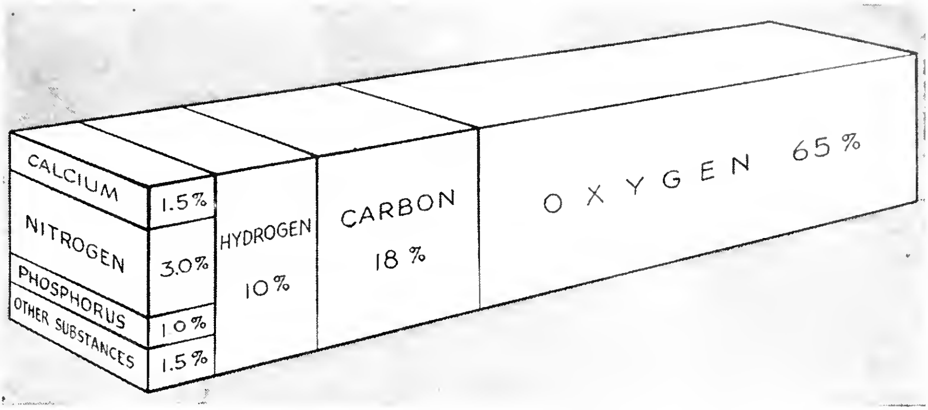
We know that we must have food to keep alive, but the connection between feeding and keeping alive is not always clear. We assume that all other organisms must also have food, although we do not recall ever seeing a plant feed. Many of us think that feeding is the same as eating. Yet the plants, and many species of animals too, have no mouths; and they must somehow take food. Is the water that a plant soaks up through its roots food for the plant? Or is the fertilizer which we place in the ground?

Since it is the protoplasm in any organism that is alive, it may help to think of food in its relation to the peculiarities and activities of protoplasm. What has being alive to do with food? What has food to do with being alive?

How Does Food Act in Living Protoplasm?

Chemical Needs From a dozen to twenty or more different chemical elements are present in the tissues of various species of plants and animals (see illustration opposite). Most of these elements are found in practically all species. But that does not necessarily mean that they are all involved in living. Nor does it mean that we or other species could live on a supply of these elements. For protoplasm is an active process in which various materials are involved, not merely a collection of those materials. Indeed, if it were possible to arrange such a collection of "elements" anywhere, no plant or animal could live in it. We know that food is the source of these elements in living bodies. But we have to ask how the various foods are related to the doings of protoplasm.

Protoplasm-Builders We may think of protoplasm as consisting basically of nitrogen-containing compounds called *proteins*, suspended in water, along with various salts and other substances, some of them dissolved in the water. The growth of protoplasm depends essentially on a supply of pro-



COMPOSITION OF HUMAN BODY

Chemically, the human body (like all other living things, for that matter) consists largely of oxygen, carbon, hydrogen and nitrogen. The proportions of the other elements vary somewhat with the kind of plant or animal, but there are always several, and certain of these have always been found indispensable whenever we have taken the trouble to experiment with them

teins, of which there are many different kinds. They all have this in common, however, that they consist of the elements carbon, hydrogen, oxygen, nitrogen and, in addition, either sulfur or phosphorus. Chemists have shown that proteins consist of combinations of simpler nitrogenous compounds called *amino-acids.* Different proteins have different combinations of amino-acids.

Proteins are thus present in almost every part of every animal or plant. That is not to say that all animal and plant materials are suitable as food. In many cases the proportion of protein is very low. In other cases additional substances present render the materials unsuitable for food, or at least for human food. It means only that protein is necessary for the making of more protoplasm.

In our common foods the proteins are represented by albumen, or white-of-egg; casein, the curd formed when milk sours; and gluten, the pasty substance in wheat flour or bread. Similar nitrogen-containing substances are present in the muscle (flesh) cells of many animals. All seeds contain some proteins, some kinds in rather large proportions—as peas, beans, peanuts, lentils and others of the bean family.

Protoplasm Action[1] In active protoplasm, as we have seen, the energy comes from the oxidation of "fuel". Protein itself oxidizes in living cells, and yields energy. In the process it is of course destroyed, breaking up into simpler nitrogen compounds, water and carbon dioxide. Other fuels, which

[1]See No. 1, p. 111.

are formed in practically all protoplasm, are represented by two classes of familiar compounds—fats and carbohydrates. We all know such fats as butter, suet, lard, olive oil, peanut oil, and others. The carbohydrates include all the sugars and starches. When fats and carbohydrates oxidize, water and carbon dioxide result.

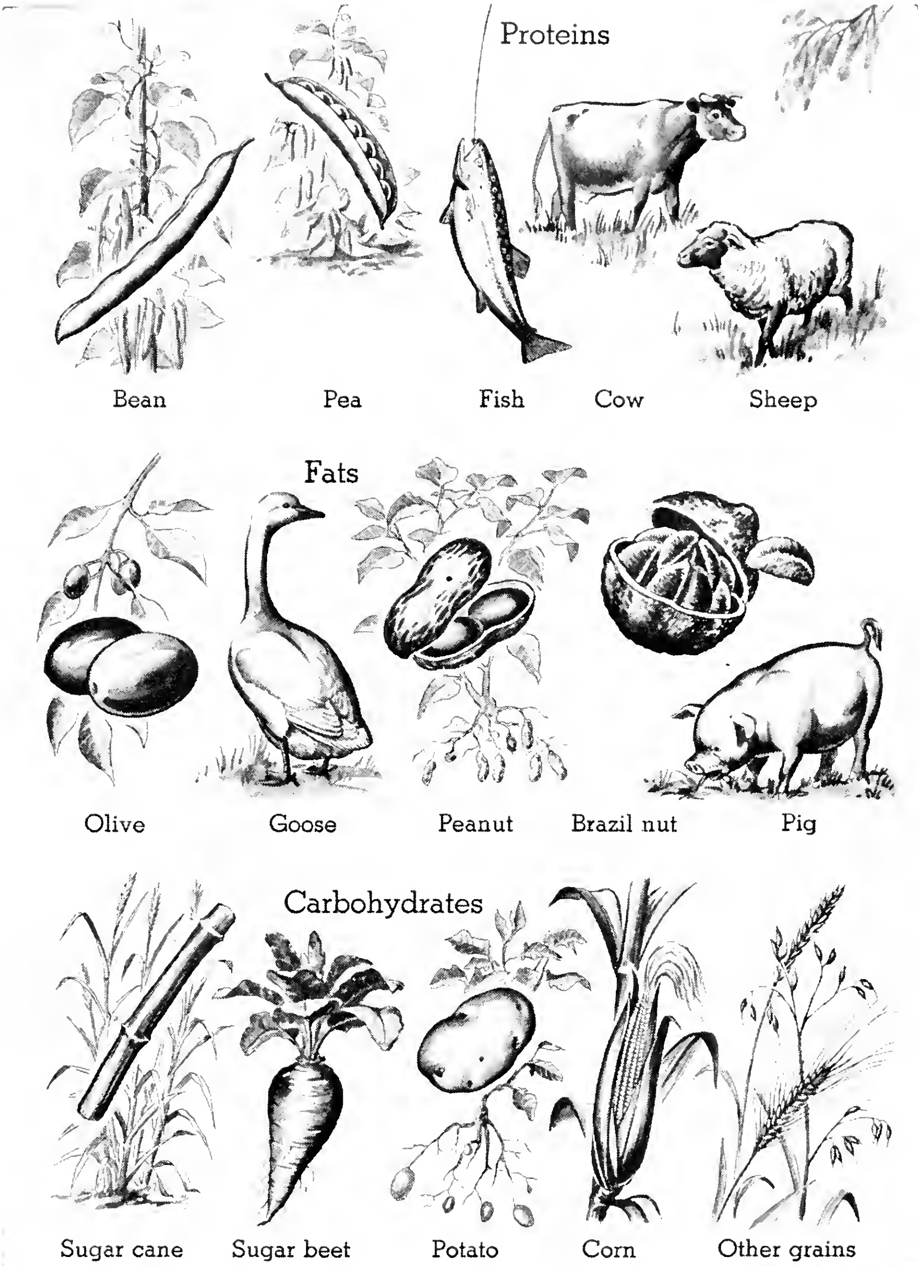
Proteins, fats and carbohydrates together are called "organic nutrients" because they occur in nature only in the bodies of living things, or organisms. Animals obtain their organic food from other animals or from plants. Green plants are able, as we shall see, to build up carbohydrates from water and carbon dioxide. They are able also to build up proteins out of these carbohydrates when they have supplies of nitrogen, sulfur and phosphorus salts. Both plants and animals are able to build fats out of carbohydrates—fats and carbohydrates consisting of carbon, hydrogen and oxygen in various proportions.

Inorganic needs Plants accordingly must receive supplies of various mineral substances, for these furnish elements used in building proteins. We have not been considering these materials as "foods" chiefly because most people, most of the time, are unaware of taking them into the body. We get practically all we need in our fruits and meat and vegetables and milk. The one great exception is common salt, which has to be added to much of our food. But even so, people do not think of salt as "food", perhaps because it is seldom that one eats salt by itself.

At any rate, these minerals are quite as essential to maintaining protoplasm as are protein and the other "organic" substances. Salts and water do not yield energy, but they make possible that complex of chemical changes in protoplasm which we call *metabolism.* Some compounds apparently act indirectly, influencing special chemical processes, just as the bromides used by the photographer slow the development of the negative.

Animals and plants naturally absorb the various elements from their surroundings, according to the composition of the sea water or of the particular soil. Calcium is more abundant in some regions, iodine is almost entirely lacking in others, and so on. Such variations must influence what the organisms take in, and may influence the way in which the protoplasm actually grows and acts.

The Soil and the Life It Sustains Studies made in Florida show that variations in the character of the soil are reflected in the plants growing on it, and that these in turn influence the cattle that feed upon them and the human beings who depend upon the plants and animals. Plants grown in some soils contain two to three times as much iron as plants of the same species grown in a different soil. Cattle that range where the salt licks are inadequate show defective bone formation and other nutritional defects. The children in such areas also have defective bone formation and have low



SOURCES OF BASIC NUTRIENTS

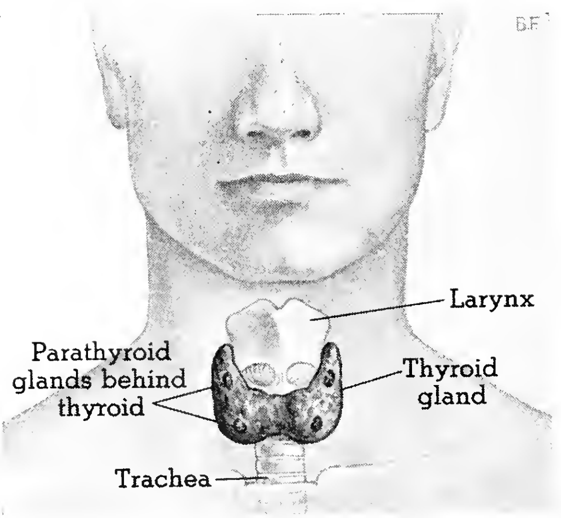
No natural food can be classed as strictly protein, carbohydrate, or fat. Nearly every animal and nearly every plant yields some of each nutrient, but seldom in proportions suitable for our needs. By using plants and animals of various kinds, we can get what we need most conveniently or most economically

hemoglobin content. Rats fed on milk from the cows in such regions show nutritional deficiencies and die in large proportions unless minerals are added to their diet.

It is possible that some of the elements or compounds which we find in various plant and animal bodies are residues of material taken in but no longer used by the protoplasm; that is, they are waste products. In some species, for example, the roots or the underground stems contain crystals of a calcium compound, calcium oxalate, which we can recognize by the acrid taste, as in jack-in-the-pulpit. These crystals may represent wastes resulting from metabolism or leftovers from processes in which the plant has more calcium than the living protoplasm can use (see illustration, p. 215).

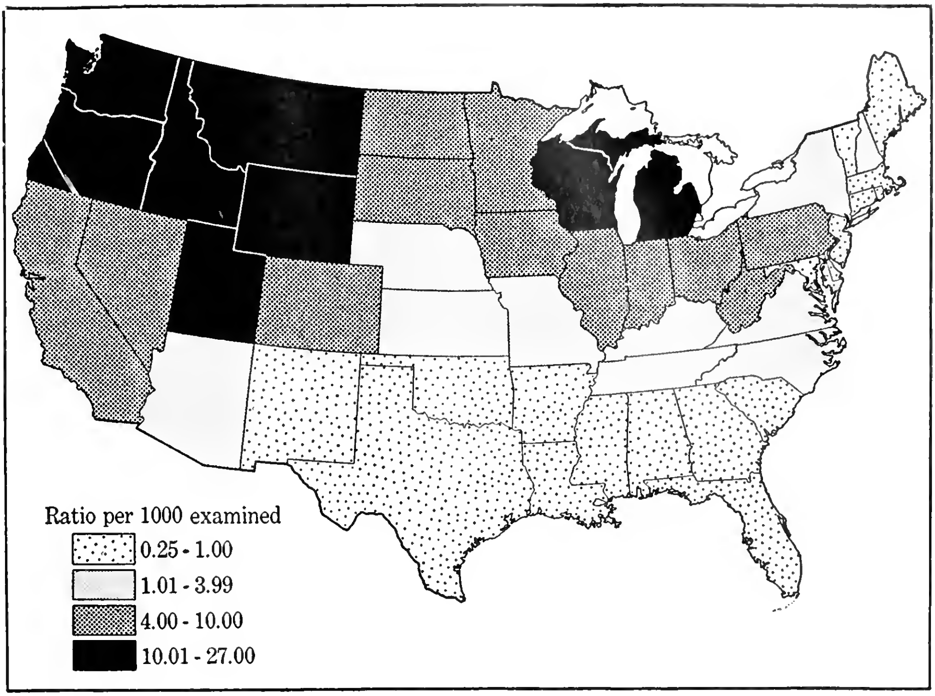
From actual experience and special experiments, we know that some of the elements found in protoplasm are indispensable—sodium, potassium, calcium, phosphorus, magnesium, iron and chlorine, for example. Where farming goes on year after year, some of the minerals from the soil are carried off with each crop. In time the soil can no longer maintain the plants. In this country, farming has in the past consisted largely of working fields until they could yield no more, and then moving on. For this reason many of the abandoned farms are quite worthless.

Special Elements Some dozen elements take part in the growth and activity of most kinds of protoplasm. In addition, many species use certain minerals in special ways. The bones and teeth of vertebrates, for example, are typically hard and rigid. We find that they contain very large proportions of calcium phosphate, which consists of calcium, phosphorus and oxygen. Again, the shells of mollusks consist of almost pure calcium car-



The food and water which the organism takes in contain a very small proportion of iodine. The product of the thyroid gland, however, the thyroxin, contains 65 per cent of iodine by weight. Apparently this gland absorbs all the iodine that the body receives and concentrates it in the thyroxin, which is essential to the normal growth and development of the organism. Unless there is sufficient iodine in the diet, the thyroid cannot make enough thyroxin. The parathyroid glands influence calcium concentration in the body fluids

IODINE AND THE THYROID



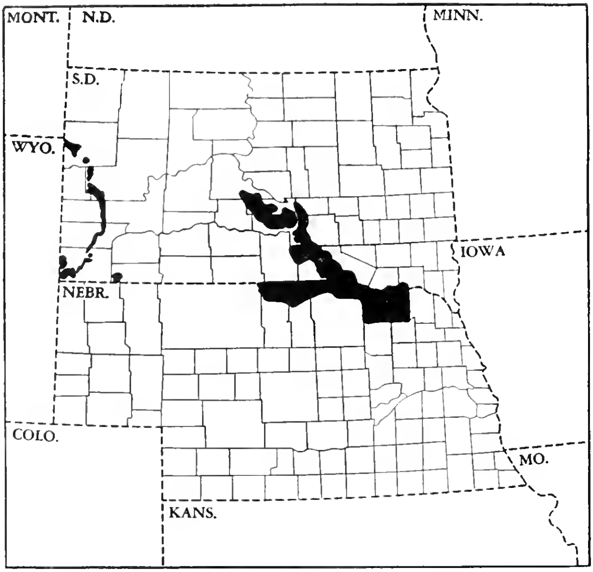
GOITER DISTRIBUTION IN THE UNITED STATES

In the First World War, drafted men from the Great Lakes region and from the Pacific Northwest had more goiters per thousand than other groups. The soils in these goiter areas contain relatively little iodine, which the body uses in making thyroxin, the thyroid hormone. It is as if the gland enlarged to keep up production from a diet deficient in iodine

bonate. The exoskeletons of crustaceans (lobsters, crabs, and so on) also contain large quantities of calcium carbonate.

Iodine, which exists in relatively large amounts in sea water, has been found to be essential in the life of land mammals and birds and other classes of animals. We should not have suspected that from the very small amounts actually present in our tissues—about forty parts per million. Iodine appears to be an essential constituent of thyroxin, which is secreted by the thyroid gland, located in front of the neck (see illustration opposite). In some mountainous regions, and in upland areas having moderate or high rainfall, the iodine has been leached out of the soil. The plants seem to thrive about as well here as elsewhere. But the animals that feed on these plants indicate the lack of iodine in their development and in their activities (see page 311).

Iron is another element present in relatively small amounts yet absolutely necessary in the metabolism of many species. In animals having red blood,



In certain portions of the North Central great plains, plants absorb enough selenium from the soil to injure animals that feed upon them. The poisoning may result in a slow disease known as "blind staggers" or as "alkali disease", or it may be quickly fatal. As a result of the selenium, the joints of the leg-bones become badly eroded. The hoofs develop abnormalities or drop off. Locomotion is impaired. The effect of the selenium persists, for the animals do not usually recover even if removed from such a region and fed a good ration

WHERE SELENIUM POISONING OCCURS

iron is an essential constituent of the *hemoglobin* (see page 205). Copper compounds are generally poisonous to most kinds of protoplasm; yet for some species copper is necessary in small amounts. Copper is an essential element in the bluish oxygen-carrier *hemocyanin* of the king crab and the lobster.

In some of the Western states the soil contains the element selenium. This element is present also in plants growing in such soil, although it does not appear to affect them in any way. But animals that feed upon such plants are often seriously poisoned (see illustration opposite). In other regions variation in the amount of fluorine in the soil may be important to us.

The element fluorine, which is very widely but unevenly distributed, seems to play a role in the assimilation of calcium and phosphorus, and so affects the formation of the teeth. A study of 7000 girls and boys of high-school age in various middle and southwestern states brought out the fact that there was much more tooth decay, or *caries*, in communities whose water supplies were free of fluorine than in communities using water with 0.5 or more parts fluorine per million parts water. Thus, the population of a certain part of Texas, Deaf Smith County, was found to have an exceptionally low number of decayed teeth; and this relative freedom from dental caries is associated with more than usual amounts of fluorine in the local waters.

In other regions unusual amounts of fluorine in the soil and soil waters apparently bring about the development of "mottled teeth" among the children living there. Nobody wants blotchy teeth, but nobody wants caries

A cow showing the characteristic symptoms of so-called "alkali disease", which killed many army horses eighty years ago. The cause of this disease has been traced only in recent times to the eating of grain or other plant stuff grown on land containing an excess of selenium. The selenium poisoning results in a poor coat, bald tail, and elongated and split hoofs

United States Dept. of Agriculture

AN EXAMPLE OF SELENIUM POISONING

either. Recent experiments have suggested that by keeping the fluorine intake at a certain level it may be possible to prevent caries, which is one of the most common "disabilities" in our population; but this amount of fluorine is not enough to cause mottling of the enamel.

Experiments have shown that boron, gallium, manganese, aluminum, and other elements play a role in the growth or activity of some organisms, although they are present in minute quantities. It is possible, however, that the various species could thrive in most cases just as well—if in a somewhat different manner—without all these rare elements.

What Are Vitamins?

How the Sailor Became a Limy During the centuries before the Christian era, when slavery was common, outbreaks of "epidemic" diseases were not rare. Some of these "visitations of the gods" spread to all portions of the population. Others, however, seemed to be restricted to the poor masses. Hippocrates (430–370 B.C.), often called "the father of medicine", described one such disease; and from his descriptions we can recognize "scurvy" as the cause of the great distress.

This disease appeared among the crusaders and on the long sea voyages that preceded and followed the discovery of America. Jacques Cartier, the French explorer who discovered the St. Lawrence River, lost 25 of his men in the winter of 1536 through scurvy, and many others were sick. An Indian told him that a water extract of the leaves of a certain evergreen tree was drunk by his people as a good medicine for that trouble. They cut down a tree and boiled the leaves; and his men recovered.

Scurvy appeared among the crowded emigrants from old countries seeking a home and fresh opportunities in the new. By the seventeenth century

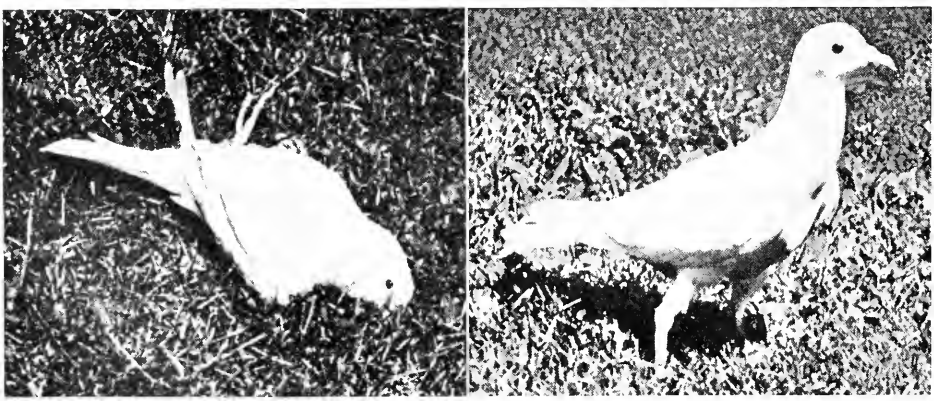
Europeans were learning through travel and trade that scurvy was due to the lack of something which soldiers and sailors and long-trail wanderers were unable to get. By about 1750 the Dutch, interested in the East Indies trade, and the British, with their expanding navy, had discovered that fresh fruit and fruit juices helped to keep their sailors well. But on long naval voyages scurvy continued to injure large numbers of the forces.

The famous Captain John Cook, in his voyage around the world, managed to keep his crew in very good condition for over three years through the use of lime-juice. For this achievement he received a medal from the Royal Admiralty in 1776. Within twenty years the use of lime-juice or lemon-juice became obligatory in all the ships of the British navy, with satisfactory results in preventing scurvy. That's how the British sailor became a limy.

For over a hundred years nobody knew just what the connection is between scurvy and lime-juice. Is it the citric acid? Is it the oil of lemon? Is it the mineral salts? Is it some of the other organic materials?

How Vitamins Were Discovered[1] Ancient Chinese records describe a disease common among poor folks who managed somehow to exist on the very edge of starvation. This is the "beriberi" of the Far East.

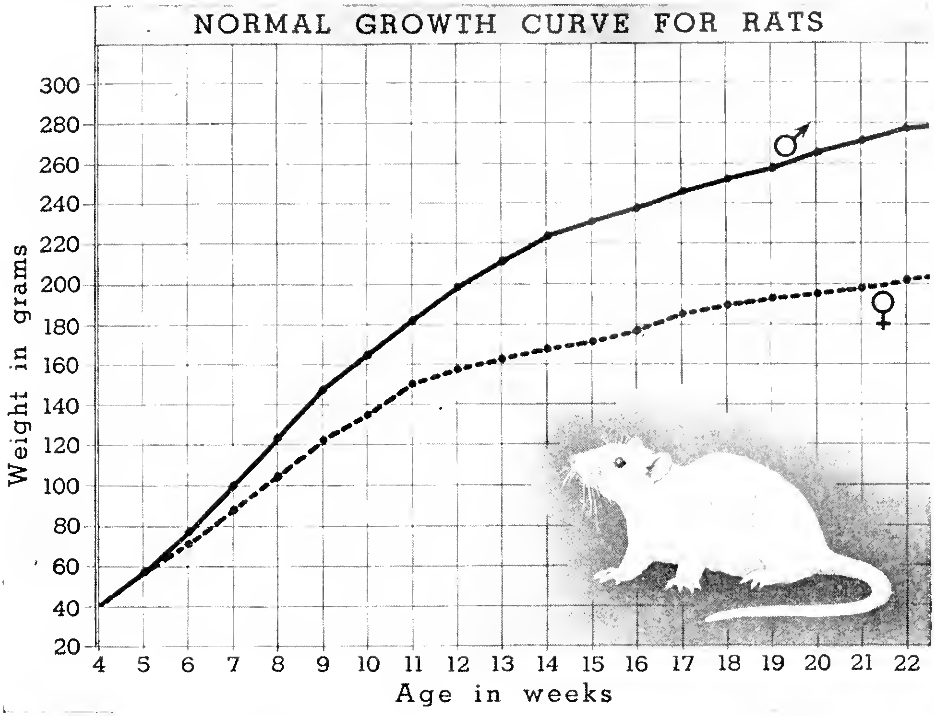
Beriberi prevailed in one situation or another in China and Japan until recent times. After Pasteur established his "germ theory", beriberi was suspected of being an infectious disease. But as Oriental physicians learned to use European methods, they made sure experimentally that this is *not* the case.



BERIBERI, OR POLYNEURITIS, IN PIGEONS

Growing pigeons fed only white, or "polished", rice and water lose appetite and weight. After a short period of time they lose control of their bodies and at times draw back their necks in typical polyneuritic fits. Such animals can be quickly restored to health by feeding them vitamin B_1 or brown rice

[1]See Nos. 2, 3 and 4, p. 112.

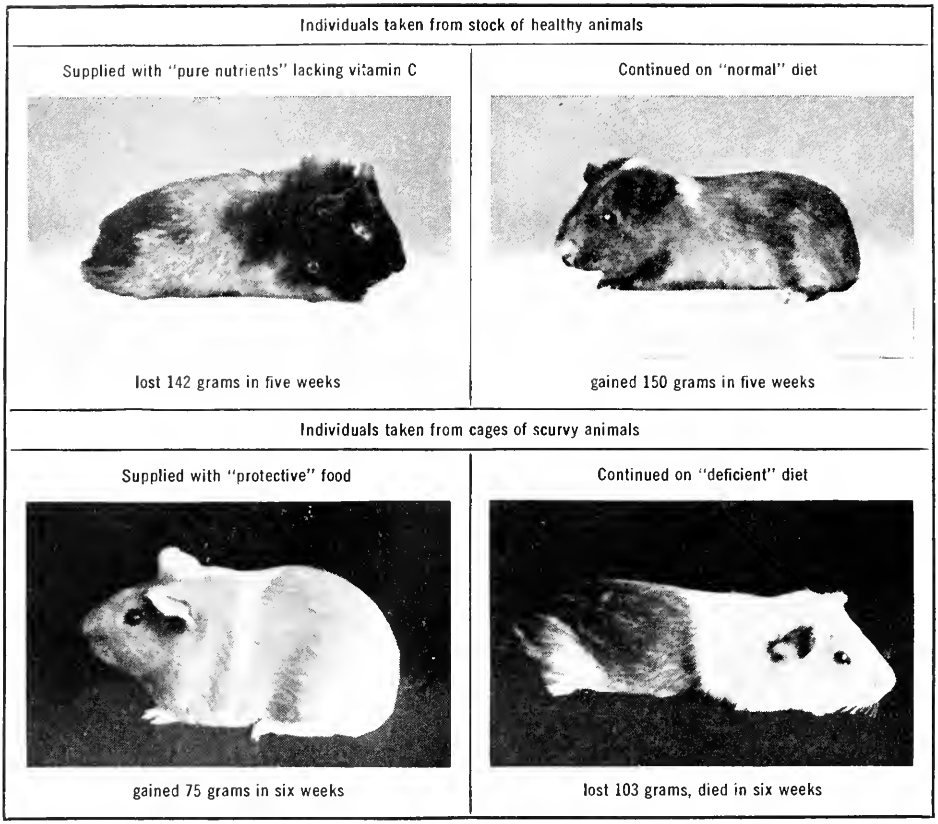


GROWTH AS AN INDEX OF NUTRITION[1]

Deficiencies in food quickly influence the rate of growth in young animals, which we therefore use for making experiments in nutrition. Rats are most sensitive to deficiencies in diet during the first twelve weeks of life, when they grow most rapidly. The curve shows the average week-by-week growth of large numbers of male (♂) and female (♀) rats kept on a suitable diet

About a third of the Japanese soldiers were on the sick list every year, suffering from this disease. Takaki, a naval surgeon, investigated the conditions in the early eighties and decided that there was nothing wrong with the climate or with the sanitary conditions. He suspected the diet. He sent two warships on a long journey. One had the usual rations, in which white, or "polished", rice was the chief ingredient. The other carried less rice, but more barley, meat, vegetables and condensed milk. On the first ship about two thirds of the men suffered from beriberi, and several died of it. On the second ship only a few sailors became sick, and they were all sailors who would not change to the newfangled diet. The Japanese government immediately ordered the new diet for all its soldiers and sailors. The men's

[1]Adapted from *Teaching Nutrition to Boys and Girls* by Mary S. Rose, The Macmillan Company. After "The Influence of Food upon Longevity" by Sherman and Campbell, *Proceedings of the National Academy of Science*, Vol. 14.



SCURVY IN GUINEA-PIGS RELATED TO DIET

When guinea-pigs or humans or monkeys are supplied diets deficient in vitamin C, they develop swollen joints. Their gums become tender and bleed easily. Hemorrhages occur readily, for the walls of the capillaries deteriorate. The flesh becomes sore and blackened when bruised. (The two animals representing each experiment were litter mates)

health improved immediately and decidedly. Yet neither Takaki nor anyone else knew just what the connection was between the new diet and the prevention of beriberi. The diet specialists thought it was the additional protein in proportion to the carbohydrates.

Toward the end of the century, however, a Dutch physician in Java, Christian Eijkman (1858–1930), attacked beriberi experimentally. He fed pigeons and chickens on "polished" rice—that is, rice from which the hulls had been rubbed off. The birds developed the symptoms of the nerve inflammations typical of beriberi. Did anything in the white rice injure the birds? Eijkman fed the sick birds rice "polishings", or the removed bran, and restored them to health. The condition was apparently due to the *lack*

of something—a something removed during the polishing. What that something is Eijkman did not know. But he showed that to keep an animal in health something is necessary besides proteins and fats and carbohydrates.

For ten or fifteen years following, Dr. Frederick Gowland Hopkins (1861–) of Cambridge University was feeding rats on a diet of the several substances that make up cow's milk. He used pure casein, pure butterfat, pure lactose (milk sugar), and the purified minerals present in milk. He tried to account for everything. While the rats fed on cow's milk thrived, those fed on the combination of purified nutrients appeared miserable and deficient. Hopkins added a few drops of "real milk" each day to their synthetic diet and made these sickly rats well again. A "balanced diet" containing the usual organic nutrients and the necessary minerals is obviously not sufficient. Something must be present in the cow's milk that is not present in the artificial combination of fats, proteins, and minerals. What was this "accessory factor", as Hopkins called it?

Later, a Polish scientist, Casimir Funk (1884–), having made similar observations in the laboratory, suggested for this "unknown something" the name *vitamine*—vital because it is essential to life; and *amine* because he assumed it to be one of a class of compounds characteristic of the structure of proteins, namely, amines or amino acids (see page 99). This name (spelled now without the *e*) has continued in use, although the substances are *not* amines at all, and although it applies to a growing series of substances.

The experimental work has continued, and has become greatly expanded. The typical procedure is illustrated by the study of scurvy in guinea-pigs[1] (see illustration opposite). Later research attempted to answer the questions How much of a given vitamin is necessary for a pound of live animal? and What is a vitamin, anyhow?

What Do Vitamins Do?

Indirect Action We know that vitamins are organic compounds which are essential in the diet of at least the higher animals. Unlike proteins and mineral salts, they cannot be considered as building materials. Unlike the other organic foods—fats, carbohydrates and proteins—they cannot be considered sources of energy. Yet without vitamins normal metabolism cannot take place.

Without increasing protoplasm or supplying energy, vitamins do influence metabolic processes. In this respect they are like the *hormones* produced within the body (see pages 302–304). Like the hormones, the vitamins produce effects highly disproportionate to the amount present.

[1]The guinea-pig is not a pig at all, but a rodent—more like a rabbit. Nor is it from Guinea, being a native of South America. Its proper name is cavy.

They seem to "regulate" or balance some of the protoplasmic activities, as certain minerals do.

Each vitamin was first known by its effects on metabolism, and not at all by its chemical nature. Investigators labeled the "unknown something" present in milk, but not present in a diet of pure nutrients, "A". The "unknown something" lacking in polished rice and resulting in beriberi and polyneuritis *when it wasn't there*, was called B. That which was lacking in food that brought scurvy was named C. As new discoveries were made, additional letters were used to designate the unknown factors. Sometimes different investigators used the same letter to designate different substances. Even today our letter designations are somewhat confusing.

Naming the Vitamins Early in the study, the vitamins were separated into two groups, those soluble in fats and those soluble in water. Feeding experiments yielded at first contradictory results because, as was later found out, the different fat-soluble substances are unevenly distributed in various foods. Accordingly the results were due in some cases to a deficiency of one factor, and in some to a deficiency of another. In 1922 the fat-soluble extract, then called A, was clearly separated into two distinct factors, now called vitamins A and D. Similarly, in the water-soluble extract then called B, a dozen or more factors have been identified by their metabolic effects.

In America the first two factors isolated from the original B extract were called vitamins B and G. In England these same factors were known as B_1 and B_2. Later, vitamin G or B_2 was found to include two or more factors. Sometimes the name was applied to riboflavin, a substance found in plants, sometimes to a product formed within the animal body by a union of riboflavin with another unknown substance. Some of the bodily disorders originally attributed to the *lack* of vitamin G (for example, the disease pellagra) were found to result from a lack of niacin.

As more vitamins came to be recognized without reference to the original fat-soluble extract or water-soluble extract, they were designated by additional letters in the alphabet. Thus, vitamin E was discovered during studies on the ripening of eggs in rats, and vitamin K was discovered in the study of the clotting of the blood. As we have come to know the chemical make-up of the various vitamins, we have substituted chemical names for the former letter designations. Thus vitamin B becomes thiamin, vitamin C ascorbic acid, and so on (see table, pp. 132–133).

Differentiating the Vitamins Most of the vitamins were discovered in connection with diseases that developed in their *absence*. We have accordingly come to think of them as *anti* this and *anti* that. In fact, we have anti-names for most of them, as well as the alphabet names. It would be more helpful, however, to think of the positive values of vitamins in normal metabolism than of the effects of their absence. This is especially im-

portant because in America people suffer much more from the "hidden hungers" of moderate deficiencies than from the so-called "deficiency diseases" (see table, pp. 132–133).

From a chemical point of view, little can be said about vitamins as a group, for each has distinct and specific characteristics and effects. Discovering a new fact about one vitamin gives no reason for presuming that it will be true of any of the others or of vitamins in general. But we are likely to group the vitamins when thinking of nutrition, since they were discovered in a relatively short time through feeding experiments with animals.

In the early attempts to *measure the quantity of a given vitamin* necessary for health, experimental animals were fed on carefully prepared diets. The first standard unit was developed by Dr. Henry C. Sherman (1875–   ) of Columbia University, as "the smallest amount of vitamin C sufficient to keep a guinea-pig of definite age and weight free from scurvy for from 70 to 90 days".

As research continued, several vitamins were identified as specific chemical compounds. So it becomes possible to make direct chemical tests in place of the long tests with living animals. Thus, Albert Szent-Gyorgyi (1893–   ), the Hungarian scientist, now living in the United States, in 1932 identified vitamin C as a definite chemical substance, ascorbic acid. The following year some Swiss chemists produced this acid synthetically. It was then possible to ascertain the amount of vitamin C, or ascorbic acid, in a food by measuring the bleaching effect on a dye. Sherman's "unit" is accordingly recognized as being equivalent to about 0.75 milligram of ascorbic acid. During the Second World War, Russian scientists demonstrated what the Canadian Indians knew four hundred years earlier, by a different name. They showed that the leaves of pines and other evergreen trees contain small quantities of vitamin C, which they were able to extract economically for the use of armies and civilian populations that could not easily get citrus fruits or tomatoes (see page 103).

The Sources of Vitamins For generations, cod-liver oil was used in European countries to help children through the dark days of winter, nobody knowing just what made this rather unpleasant stuff so valuable until vitamins A and D were discovered in our own time. During the Second World War it became impossible to get supplies of this oil, but almost immediately a new industry developed off the eastern shores of Florida—that of catching sharks for the oil in their livers. Incidentally, every bit of the animal is used in one way or another, from the hide, made into tough leather, to the last scrap of flesh used for dog food, poultry food and fertilizer.

Vitamins seem to have their beginnings in plants. Vitamins present in animal tissues are derived from plants or from substances formed in plants.

Most herbivorous animals and some carnivorous animals, like man, are able to produce vitamin A from *carotin*. Other carnivorous animals—cats, for example, and carnivorous fish—lack what it takes to transform carotin into vitamin A.

In both plants and animals vitamin D results from the action of sunlight on ergosterol, a fatty substance. Ergosterol, however, originates, so far as we know, only in plants. Many mammals (though not man, the monkey, or the guinea-pig) are able to synthesize ascorbic acid.

The cow can thrive without taking vitamin B in her food. Apparently, certain species of bacteria that live in the rumen, or paunch, of the animal's complex "stomach" are able to make thiamin out of other materials. Experiments have been carried on to see whether it is possible to domesticate such bacteria in the human intestine and so make it unnecessary for us to get thiamin with our food.

Our knowledge of the functions of the vitamins in the animal body is dependable, so far as it goes. However, not all the vitamins have been clearly identified as definite chemical compounds. Until we are sure that all the substances that are known by a particular name really are *the same substance*, we cannot be sure that the effects observed in organisms are always due to the vitamin (or whatever other class of materials) to which we have attributed them.

Until recent years the various vitamins have not been available in large quantities. However, improved methods of isolating or producing them are being developed. With adequate supplies of pure materials, and with improved techniques for dealing with them, we may hope to solve many of the outstanding nutritional problems. At the same time, having large quantities of certain vitamins enables us to remedy deficiencies in diet among masses of our population.

With all these gains, there is real danger. For we are all naturally impressed by the dramatic achievements of "vitamin cures". People may too easily get the idea that we can prevent or cure all sorts of ills by feeding ourselves assorted vitamins by the spoonful or in capsules. The indiscriminate use of vitamin concentrates for self-medication may introduce other privations or deficiencies, as well as positive injuries. We are not yet certain what effects various vitamins may produce if used in excessive quantities. Moreover, people can generally use their food money to better advantage by going to natural foods for the vitamins they need. We cannot afford to pay caviar prices for cabbage leaves.

During the Second World War the British Ministry of Health conducted two series of experiments to find out whether vitamin concentrates were of any help to school children or to workers. Over a period of from two to nine months, hundreds of children and of workers were supplied

vitamin tablets in addition to the regular rationed diets, and equal numbers had only the regular diets. Height, weight, and sickness records showed no difference whatever between the two groups. A suitable diet needs no supplement; a diet that is not suitable should be replaced with one that is.

In Brief

Body-building, energy-yielding, and regulative nutrients are essential to all living protoplasm.

Proteins, the nitrogen-containing nutrients, serve both as protoplasm-building and as energy-yielding material.

Fats and carbohydrates supply energy only.

Certain chemical elements are indispensable to protoplasm; if soils or food lack any of these, the growth of living organisms is limited.

Several minerals are essential to the growth activities of many kinds of protoplasm; some minerals are used in the formation of special tissues, such as bones or shells.

Some of the mineral substances found in cells are probably waste products; others may be injurious substances separated out of the protoplasm.

Normal development of living organisms depends upon the presence in the diet of minute traces of certain "regulative" substances.

Vitamins have been associated with extremely abnormal symptoms developed by organisms entirely deprived of them, and have received anti-names. Moderate deficiency is more common, and has been widely remedied by supplying adequate amounts of the various vitamins.

The ultimate sources of vitamins are plants.

Present knowledge indicates that with a little care adequate amounts of all the vitamins can be obtained in natural foods, so that we do not generally have to depend upon the drugstore for these substances.

As we come to know the specific composition of vitamins, we can use chemical tests for their presence in foods instead of tests on experimental animals.

EXPLORATIONS AND PROJECTS

1 To find the effect of a diet deficient in energy, feed two rats three to four weeks of age all they will eat of the complete diet given in footnote 2, p. 112, and feed two other rats just $\frac{2}{3}$ as much of the same diet in proportion to their weight. About 0.12 gram per gram of rat per day should hold their weight nearly constant. At the end of four or five weeks, give the low-energy animals all the food they will eat and see whether they catch up with the control animals. Record and graph daily weights; interpret results.

2 To find the effects produced when pigeons are fed diets lacking thiamin (vitamin B), feed one young pigeon brown rice and water and another white rice and water—that is, a diet lacking thiamin. Keep a daily record and graph of the food consumed and of the weight of each pigeon. Should the growth curve of the pigeon on white rice drop sharply, give close attention to the animal, as polyneuritis and death will result if the animal is kept on this diet too long. The pigeon may be saved, even after polyneuritis develops, if it is promptly given thiamin. What effect does a lack of thiamin have upon the appetite? What abnormal effects does a lack of thiamin produce?

3 To find the effect of a diet deficient in ascorbic acid feed one of two guinea-pigs, weighing approximately 300 g each, a complete diet and the other a diet lacking ascorbic acid.[1]

Keep a record of weights and make a graph showing the growth curve of each animal. Compare results in weight and appearance and note conclusions.

4 To find the effects of vitamin A and thiamin deficiencies, keep three pairs of rats on diets having vitamin differences. Keep one pair of rats, from three to four weeks old, on a complete diet; one pair on a similar diet lacking vitamin A; and the third pair on a similar diet lacking thiamin. All the conditions for the three pairs should be exactly the same, except for the variations in the diet.[2] Weigh weekly for six weeks and plot the growth curve of the rats on each diet. Compare results and note conclusions.

[1]This diet consists of a mixture of rolled oats and bran, equal parts by volume, 50 g; skim-milk powder (heat for 4 hr at 110° C), 30 g; butter, 10 g; and table salt, 1 g. For the normal, or control, diet use the same combination but add 10 g or more of spinach or other greens, or 1 mg of pure ascorbic acid (vitamin C) daily. Prepared rabbit foods on the market are complete in every essential but ascorbic acid, and may be substituted for the mixture given above in performing this experiment.

[2]Formulas for rat diet:

DIET I COMPLETE	DIET II LACKING THIAMIN	DIET III LACKING A
Meat residue or casein, 18 g	same, but *vitamin-free*, 18 g	same, but *vitamin-free*, 18 g
Cornstarch, 48 g	same	same
Hydrogenated fat, 8 g	same	10 g
Cod-liver oil, 2 g	same	*none*
Salt mixture, 4 g	same	same
Yeast, dried baker's, 20 g	same, but *autoclaved*, 20 g	same

Note that hydrogenation of oils results in solid fats. Hydrogenated cottonseed oil is commonly used as shortening in place of lard and other solid fats.

A good salt mixture to use contains in each 100 g: 5 g NaCl, 16 g $MgSO_4 7 H_2O$, 10 g $NaH_2PO_4H_2O$, 28 g K_2HPO_4, 38 g calcium lactate, 3 g iron lactate.

Note that the thiamin-deficient diet (Diet II) is the same as the complete diet except that the protein is vitamin-free and the yeast is autoclaved (that is, heated at 110° C for 4 hr) to destroy the thiamin.

Note that the vitamin-A-deficient diet (Diet III) is the same as the complete diet except that the protein is vitamin-free and the cod-liver oil (source of vitamin A) is omitted.

1 What are the different functions that foods perform in the body?

2 What functions do all nutrients have in common?

3 What substances are sometimes deficient in a diet which furnishes plenty of energy-yielding material?

4 What elements, sometimes lacking in soils, so modify the food content of plants as to limit the growth of animals which feed upon them?

5 What are the special functions in animal bodies of such minerals as iodine, calcium, phosphorus and iron?

6 What known vitamins are essential to the normal development of organisms?

7 What are the sources of all vitamins?

8 How can each of us be sure that he gets an adequate supply of the various regulative substances which he needs?

9 Why do so many of the vitamins have anti-names?

10 What are some of the specific dangers that we now face in our use of the various vitamins?

CHAPTER 7 · WHAT KINDS OF STUFF SERVE AS HUMAN FOOD?

1. Can we trust our instincts or feelings in deciding what to eat and how much to eat?
2. Can we live on vegetable diets only or on meat only?
3. Will eating meat make us strong?
4. Does sugar yield quick energy?
5. Are "sweets" harmful?
6. Do restaurants and hotels serve balanced meals?
7. What foods are fattening?
8. How did our grandparents get along without knowledge of vitamins?
9. Are irradiated foods better than others?

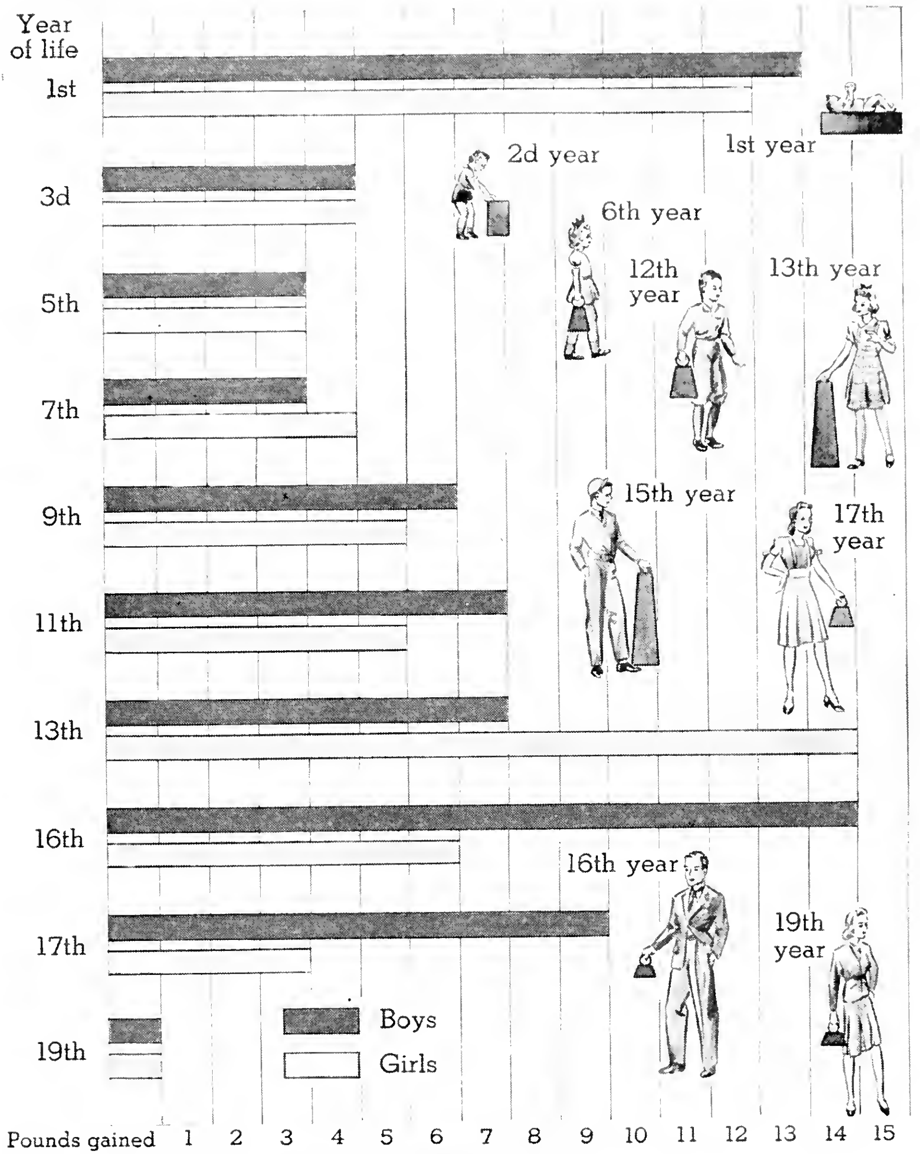
We should expect that in half a million years or more the human race might have learned all there was to know about what to eat and how to eat it. Most people, however, do not know, either from instinct or from daily experience, the best way to manage their personal food problem. Everywhere children suffer from defective nutrition, and grown folks from disturbances of digestion. Starvation and overfeeding exist side by side. In the course of ages we have found that some parts of animals and plants (muscle, grain) are better than others (hide, wood). Customs have selected the plant and animal materials that are most valuable as food—in any given region. We are constantly discovering useful food plants and food animals. But experience has not taught us the best proportions or combinations of meat and grain and fruit for bodily comfort and efficiency.

What Are the Food Needs of the Body?

Energy to Keep Going Like all chemical processes, metabolism results both in breaking down some compounds and in building up other compounds. Metabolism leads in part to the formation of new protoplasm and tissues, and in part to the breaking down of proteins and other complex substances.

The rate at which the chemical transformation or metabolism goes on varies from one kind of tissue to another. It varies also with the activity of the body from time to time. In a person running to a fire, the chemical activity is high. During sleep or rest the metabolism is at its lowest level, and is pretty constant. This low, constant level represents the basic need for energy.

The amount of food one needs for growth varies in the course of his lifetime. During the first year of life the baby grows very rapidly (see illus-



AVERAGE ANNUAL GAINS IN WEIGHT

Men and women attain adult size during the first eighteen years of their life. The gain is exceptionally rapid during the first year and again during adolescence. Twelve-year-old and thirteen-year-old girls are larger than boys of the same age, for they grow faster during the twelfth year. The boys, however, overtake them during the fifteenth year and get progressively farther ahead during the fifteenth to the eighteenth year. (The weights represent gains in weight)

tration, p. 115). The baby's parents have already attained their full growth. The amount of food that a person needs to make up for the heat radiated from the surface of the body varies with the size and also with the shape of the body (see illustration opposite). The smaller a child, the more surface he has in proportion to his body weight, and hence he loses relatively more heat. By actual measurement, a one-year-old child needs approximately twice as much energy per pound of body-weight as does an adult.

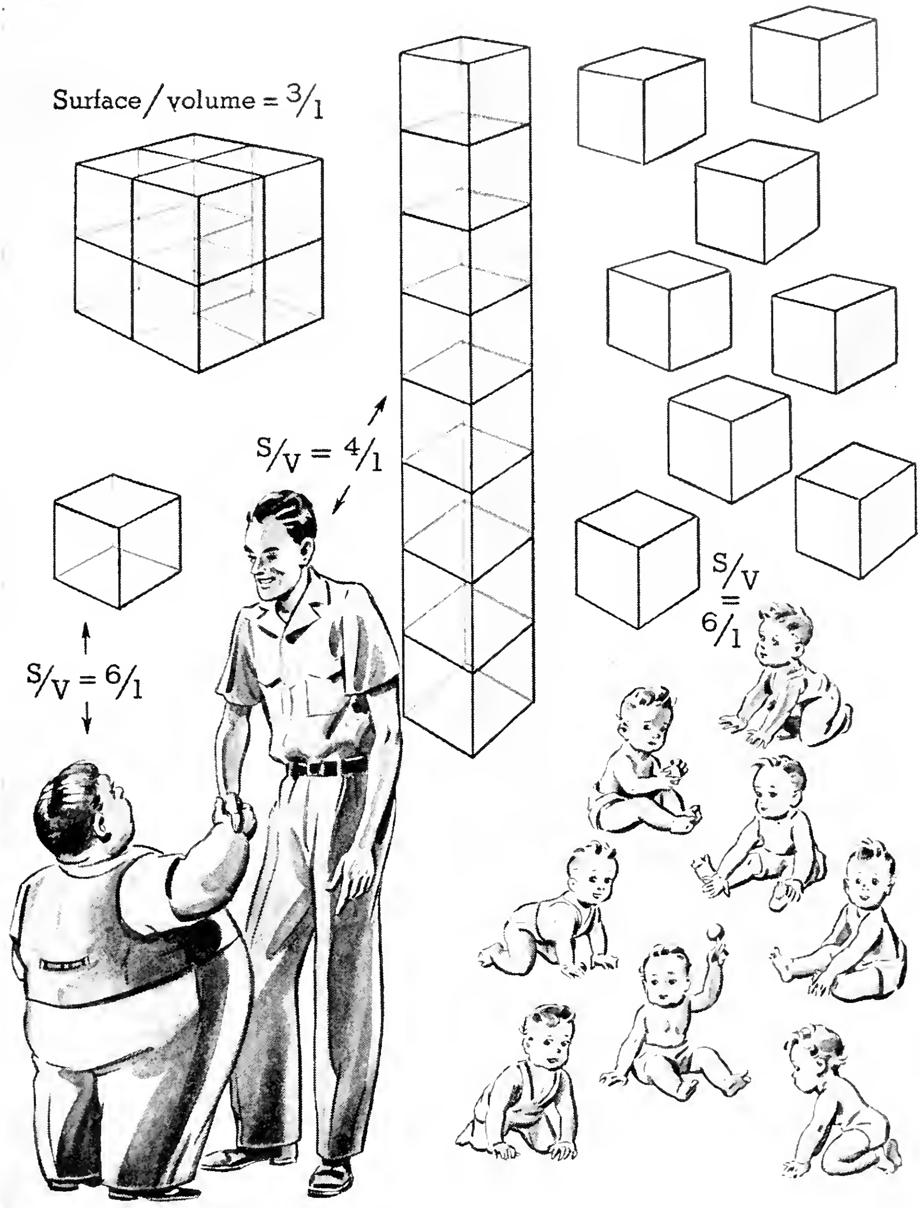
Energy needs are indirectly related to sex. Girls and women have a thicker layer of fatty tissue beneath the skin than boys and men. This fat prevents rapid radiation of heat from the body. It is interesting to recall that most long-distance swimming records are held by women rather than by men. Exposure also affects the body's loss of heat. The body loses heat faster in a cold, dry, windy climate than in a warm, moist climate. Clothing and shelter are, of course, factors in the loss of heat.

Circulation of the blood, breathing, and other processes are continually going on when the body is at rest. "Warm-blooded" animals maintain a constant temperature. The heat continually radiating from the surface is constantly being replaced. Muscular movements are continually taking place in the digestive organs, and energy is used in various other ways within the body. From 40 to 50 per cent of the body is made up of muscular tissue. The bulk of this tissue is attached to the skeleton and is used in standing as well as in locomotion and other voluntary actions. At all times, even when these muscles are relaxed, energy is used in keeping them somewhat on the stretch.

Above the Base Line The amount of energy that the body uses, even while it is "doing nothing", is constantly influenced by two sets of factors. Digesting food involves a measurable amount of energy. Thus the body uses about 6 per cent more energy soon after a meal, when the digestive organs are most active, than just before a meal, when digestion is practically at a standstill.

When you are sitting and reading, or when you are standing quietly, your body uses about one-and-a-third times as much energy as it does while sleeping. Walking at a moderate pace uses about two-and-a-half times as much; running uses about seven times and stair-climbing about fifteen times as much.

Unit of Energy To measure the energy expended by the living body, we use a unit developed by engineers. This is the *Calorie* (Cal), and, like the more familiar foot-pound (ft-lb) used in measuring work, it is composed of two factors. We measure work as if it always consisted of some quantity of matter (pounds) moving a certain distance (feet). In a similar way we measure heat as a quantity of matter, for example, 1 kilogram (kg) of water, being heated a certain "distance" (1 degree on the centigrade scale).



SURFACE DEPENDS UPON SIZE AND SHAPE

A 1-inch cube exposes 6 square inches of surface. Eight such cubes combined into a single large cube expose 24 square inches of surface; when arranged in a tall column, 34 square inches; and when scattered separately, 48 square inches. Similarly, a tall person weighing 160 pounds exposes more surface than a stocky person of the same weight, but decidedly less than eight babies weighing 20 pounds each

For very delicate work, a smaller unit is used, sometimes called the "small calorie" and spelled by the engineers with a small c; this is the gram-degree calorie, and is of course only one thousandth of a Calorie. We measure fuel or energy value of foods in the "large Calories"; but in ordinary reports and tables people do not generally make a point of spelling *Calorie* always with a capital.

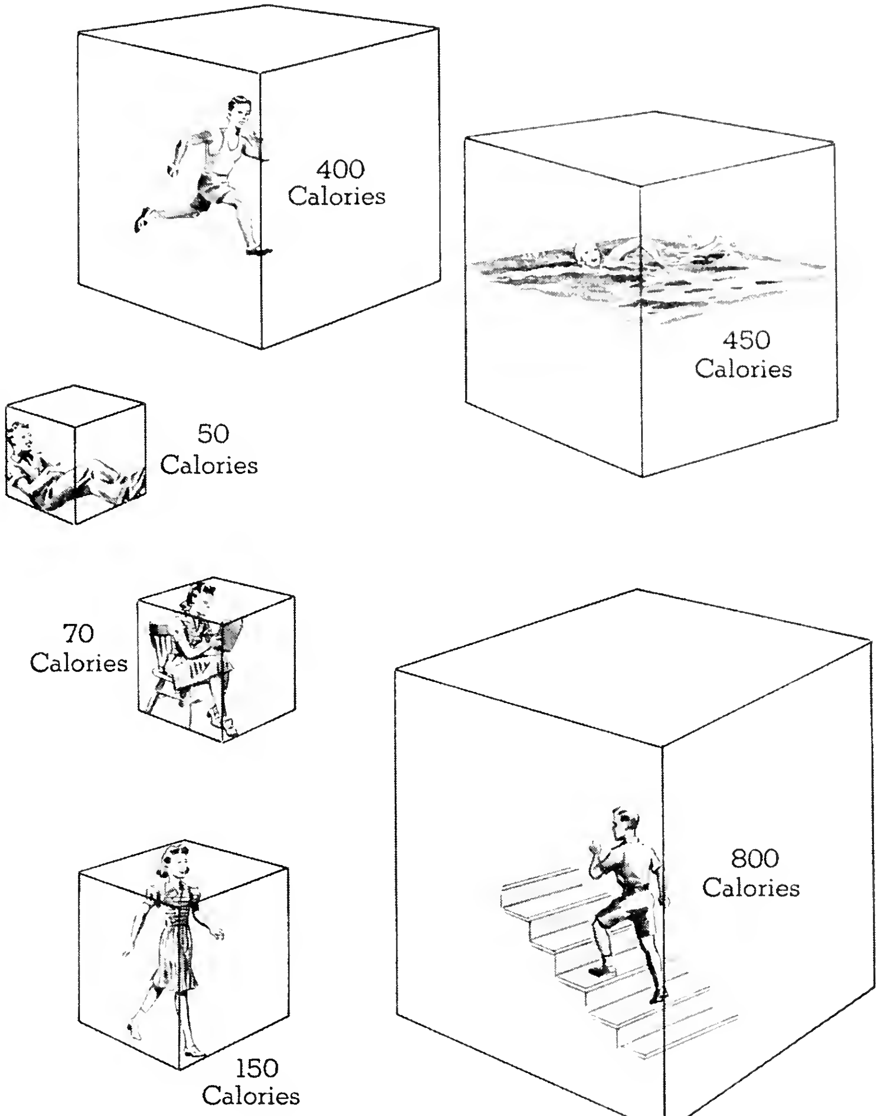
Measuring the Body's Work[1] For finding out how much energy an organism actually transforms in a given time, the respiration *calorimeter* was developed about the beginning of the century. Later types of calorimeter are all based on the general fact, established by experiment, that the amount of energy set free by an organism is in *direct* proportion to the amount of carbon it oxidizes. Accordingly, if we knew the exact amount of carbon dioxide that a person breathed out in one day, for example, we should be able to calculate the total amount of work he had done. But the calorimeter measures this "work" as a physical fact—that is, as calories or as foot-pounds—not as useful products, words written, nails driven, or buttons sewed.

The calorimeter has been of tremendous help in solving many problems of nutrition, as well as problems of metabolism, under various exceptional conditions, including illness. For example, it has been indispensable in developing high-altitude and stratosphere flying, in which the fliers are supplied with oxygen in measured quantities. As the calorimeter becomes more widely used in hospitals, in mining, and in industry, simpler types are developed, and simpler procedures too. Thus, we can determine the amount of heat a person generates by measuring the amount of oxygen he consumes —for under controlled conditions the body liberates 0.004825 Calorie for each cubic centimeter of pure oxygen (see illustration opposite).

Basal Metabolism It is extremely difficult to measure a person's constant, or basic, metabolism during sleep. Investigators and medical men have therefore agreed upon an *arbitrary* measure which is called *basal metabolism*. This is the rate of energy expenditure by a person who is awake, lying still and relaxed, and who has not eaten any food during the preceding twelve hours. It is customary to take these tests early in the morning before the patient has had any breakfast. This is the nearest approximation to basic metabolism that can be obtained with any device other than the respiration calorimeter, of which there are but a few in the country.

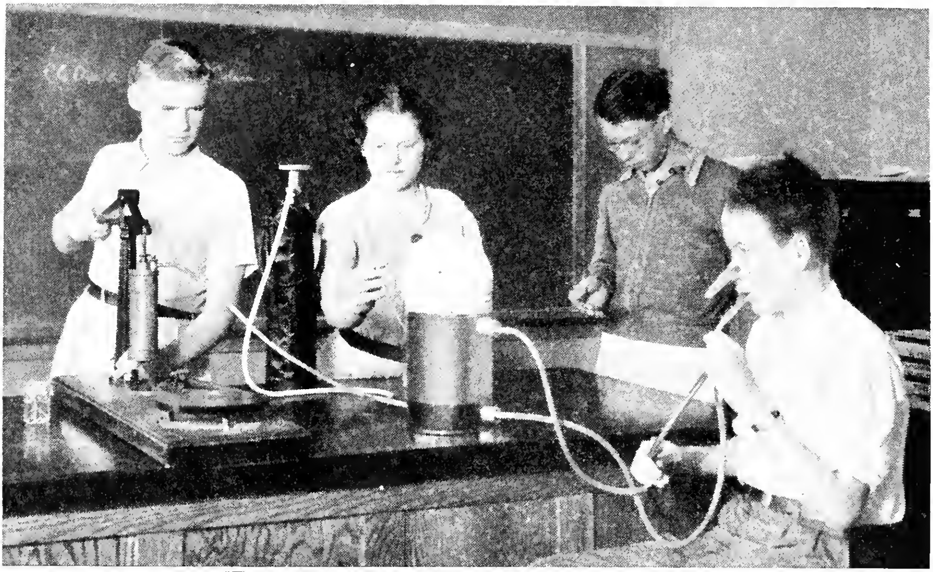
Standards for Boys and Girls[2] The basal metabolism measurement has been made with calorimeters on thousands of boys and girls. For comparison, the results are calculated to show the daily need "per pound of body weight" (see table, p. 121). Since these figures represent *averages*,

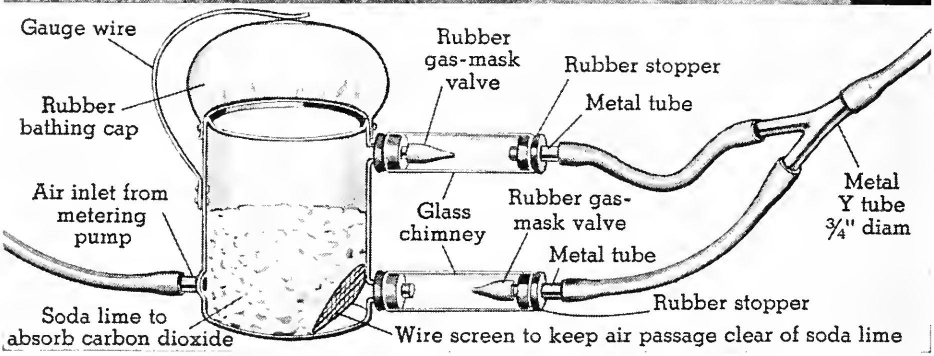
[1]See No. 1, p. 135. [2]See No. 2, p. 135.



ENERGY EXPENDITURE UNDER VARIOUS CONDITIONS

Experiments have shown that a 110-pound boy or girl uses 50 Calories per hour under "basal" conditions. When sitting or walking, one uses much more energy. When one is engaged in strenuous activity, such as running, swimming, or climbing stairs, he spends energy from eight to sixteen times as fast as when he is asleep





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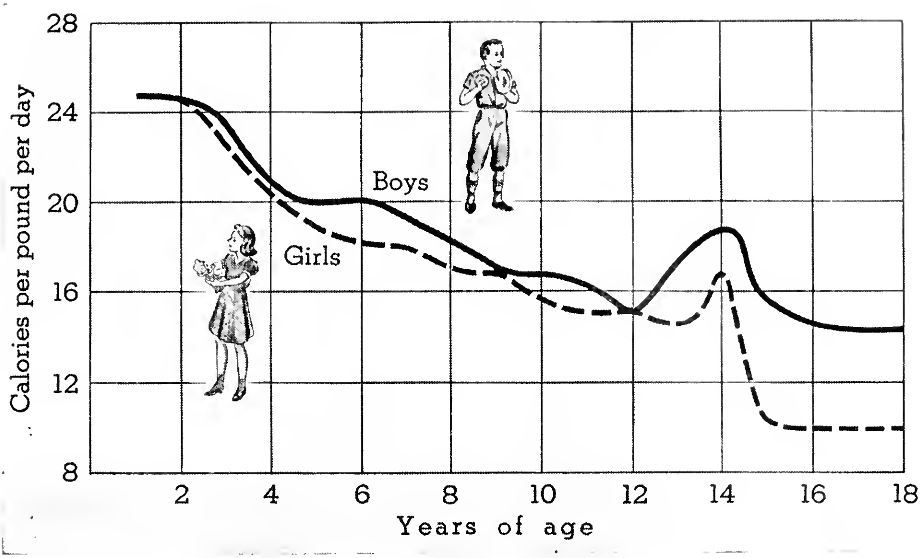
HOMEMADE RESPIRATION CALORIMETER

Energy expenditure of the subject while sitting is measured by the oxygen he consumes in a given time. The calorimeter is first filled with oxygen from the cylinder. The subject then starts breathing from the calorimeter. The quantity of gas in the calorimeter is adjusted with the pump so that the rubber cap just touches the gauge wire each time the subject exhales. The number of pumpfuls of air put in to make up for the oxygen used by the subject is recorded. One member of the crew keeps time

they do not exactly fit any particular individual. However, they do indicate pretty closely one's basal needs. Thus a girl of 14 who weighs 90 lb and who is lying still and "doing nothing" would have to take in fuel food equivalent to $(90 \times 17) = 1530$ Calories per day just to keep alive. Everything she does above that calls for additional energy—additional food.



AVERAGE DAILY ENERGY EXPENDITURE AT DIFFERENT AGES[1]

The high expenditure of energy per pound of body weight during the first year is due to the relatively large body surface and to very rapid growth. The increased energy expenditure between twelve and fifteen years of age is due to accelerated growth at this time

Average Basal Energy Metabolism of Boys and Girls in Terms of Body Weight[2]

AGE IN YEARS	CALORIES PER POUND PER DAY		AGE IN YEARS	CALORIES PER POUND PER DAY	
	Boys	Girls		Boys	Girls
1	25	25	10	17	16
2	25	25	11	16	15
3	23	22	12	15	15
4	21	20	13	18	14
5	20	19	14	19	17
6	20	18	15	16	11
7	19	18	16	15	10
8	18	17	17	14	10
9	17	17			

Energy Cost of Activities[3] By the use of the respiration calorimeter the energy cost of several different activities has been worked out. These figures tell us how many additional Calories an individual spends per

[1]After *Foundations of Nutrition* by Mary Swartz Rose. By permission of The Macmillan Company, publishers.

[2]Adapted from Mary Swartz Rose, *Foundations of Nutrition*, 1938, p. 90. By permission of The Macmillan Company, publishers.

[3]See No. 3, p. 136.

pound of weight per hour of activity, *above basal metabolism.* A few of these are given in the accompanying table.

Energy Cost of Activities[1]

ACTIVITY	CALORIES PER POUND PER HOUR	ACTIVITY	CALORIES PER POUND PER HOUR
Bicycling (racing)	3.4	Sawing wood	2.6
Bicycling (moderate speed)	1.1	Sewing, hand	0.2
Carpentry, heavy	1.0	Sitting quietly	0.2
Cello-playing	0.6	Standing relaxed	0.2
Dancing, fox trot	1.7	Swimming (2 miles per hour)	3.6
Dancing, waltz	1.4	Typewriting rapidly	0.5
Dishwashing	0.5	Violin-playing	0.3
Dressing and undressing	0.3	Walking (3 miles per hour)	0.9
Eating	0.2	Walking rapidly (4 miles per hour)	1.5
Fencing	3.3	Writing	0.2
Ironing (5-pound iron)	0.5		
Playing ping-pong	2.0		
Running	3.3	Energy saved during sleep	0.05

Daily Energy Needs of Boys and Girls Boys and girls of a given age differ in size, and they differ in amount of activity. It is nevertheless helpful to know the *average* requirements for large numbers, as given in the table below. If a boy is both active and large for his age, his daily food needs will be near the upper limit. If a girl is active but small, her energy requirements will be about midway between the extremes given for her age.

Average Number of Calories Needed Daily[2]

AGE IN YEARS	CALORIES PER DAY		AGE IN YEARS	CALORIES PER DAY	
	Boys	Girls		Boys	Girls
1	900–1200	800–1200	10	2100–2700	1900–2600
2	1100–1300	1000–1250	11	2100–2800	2000–2800
3	1100–1400	1050–1350	12	2300–3000	2100–3000
4	1200–1500	1150–1450	13	2500–3500	2300–3400
5	1300–1600	1200–1500	14	2600–3800	2400–3000
6	1500–1900	1450–1800	15	2700–4000	2400–2800
7	1600–2100	1500–1900	16	2700–4000	2250–2800
8	1700–2300	1600–2200	17	2800–4000	2250–2800
9	1900–2500	1800–2500			

[1]N. Eldred Bingham, *Teaching Nutrition in Biology Classes.* A Lincoln School Research Study, Bureau of Publications, Teachers College, Columbia University, 1939, p. 50. Adapted from Mary Swartz Rose, *Foundations of Nutrition*, 1938, pp. 606–607. By permission of The Macmillan Company, publishers.

[2]Henry C. Sherman and Caroline S. Lanford, *Essentials of Nutrition*, 1943, p. 84. By permission of The Macmillan Company, publishers.

Energy Needs of Different Workers We should expect that a person working in the steel mills expends more energy than a clerk who sits at a desk making out payrolls. The energy needs for various kinds of work are given in the table below, which combines the results of many studies. Men and women of above-average weight require more than indicated; similarly, men and women of light weight need less.

Energy Needs and Kinds of Work[1]

KIND OF WORK	DAILY CALORIE ALLOWANCES	
	For Men of Average Weight (154 lb) Ages 20–59	For Women of Average Weight (132 lb) Ages 20–59
Very active work—rapid heavy lifting or pulling with exposure to weather	4500	3000
Moderately active work—standing or walking with moderately heavy loads	3000	2500
Light work—seated with considerable arm or leg movement, or standing and walking with little lifting or strain	2700	2300
Sedentary work—seated, involving little arm or leg movement	2400	2100

Building Stuff Like all other living animals, the human organism needs proteins and minerals out of which protoplasm develops new tissues (see pages 96–97). The body makes use of a wide variety of proteins, although some are more completely used than others. Proteins differ in the proportions of the amino-acids they contain (see page 97). The combination of amino-acids found in the protoplasm of any species differs somewhat from that found in other living things. Those proteins which are most like human protoplasm are most usable in the growth of new body tissues.

The mineral needs of the body are also essentially the same as those of other animals. It is significant that a newly born child is relatively poor in calcium and rich in iron. Furthermore, the skeleton, composed largely of calcium and phosphorus (see page 100), gets most of its growth during the first eighteen years of life. Nearly one third of the phosphorus found in the body is in the muscles and other soft tissues, which also develop rapidly during the first years of life. Thus growing children require relatively more calcium and phosphorus than adults. Although the iron in the body is but a small quantity, its function in respiration does not permit a shortage (see page 101). Some diets are inadequate in this respect.

[1]Hazel K. Stiebeling and E. F. Phipard, *Diets of Families of Employed Wage Earners and Clerical Workers in Cities*, United States Department of Agriculture Circular No. 507, 1939.

Studies of American diets indicate that, with the exception of iodine (see pages 100–101), the foods usually eaten contain adequate supplies of the remaining salts essential to our protoplasm.

Chemical Regulators We have seen that various inorganic substances play an important role in the building and in the activities of protoplasm. In addition, however, mineral salts appear to be important because their relative *concentration* in the cells and body fluids affects osmosis and the distribution of material (see page 87). The rhythmic contraction and relaxation of heart muscle depends upon certain *proportions* of calcium, sodium and potassium in the body fluids (see page 99). When the supply of calcium is too low, body muscles become tense and rigid; some convulsions are caused in this way. Other salts affect the oxidation of food in the cells. When the concentrations or proportions of these salts fluctuate too much, the metabolism is disturbed.

How Can We Plan a Diet to Suit Our Body Needs?

More than Day by Day We usually know immediately whether our food pleases us or when our hunger has stopped. If something goes wrong with the digestion, we soon discover it. But we may continue a very long time on a diet that is seriously lacking in essentials, without realizing it. For this reason it is important that everybody acquire food preferences and food practices guided by reliable knowledge of daily needs. Such knowledge rests upon studies of what people do actually eat and upon experiments with the diet and its effects on college students, soldiers and other people, and on various animals.

In discussing metabolism and life needs so far, we have said very little about food: we have considered only such abstractions as Calories, proteins or vitamins. When we sit down to a meal we see none of these things; we are confronted instead with various breadstuffs, fruits, vegetables, meats, and the like. We know that some of the foods which we use contain more of the essentials than others (see illustrations, pp. 126 and 127). How can we translate the products of the food factories and the kitchen into proteins and Calories and vitamins? The information which we need for such translating has been furnished by research workers in government laboratories, in hospitals, in universities, and in other institutions. It is available to us in convenient tables that have been prepared by various experts.

Food Groups[1] We group or classify the common foods according to what they furnish in our diet.

[1]See Nos. 4 and 5, p. 136.

1. Breadstuffs and other grain products are economical sources of energy and proteins and vitamins, but lack proportionate amounts of mineral.

2. Starches and sugars (carbohydrates) are concentrated sources of energy but furnish nothing else to the diet.

3. Fats are even richer fuels, yielding approximately two-and-one-fourth times as much energy as the same quantity of carbohydrates or proteins.[1] Some fats, especially yellow fats, contain vitamins A and D.

4. Meats, including fish and poultry, are rich in proteins and energy, but, in general, are deficient in minerals and vitamins.

5. Fruits and vegetables vary greatly in their protein and energy values, but are excellent sources of mineral elements and vitamins.

6. Milk forms the most nearly perfect human food we know. Milk and milk products furnish high-quality proteins, much like those found in the human body. Milk contains all the essential mineral elements and all the essential vitamins. It can be considered the most valuable of all foods for making up for any deficiencies in the diet.

7. Eggs are high in nutritive value, are rich sources of high-quality proteins, of phosphorus, and of vitamins A, B, D, and G.

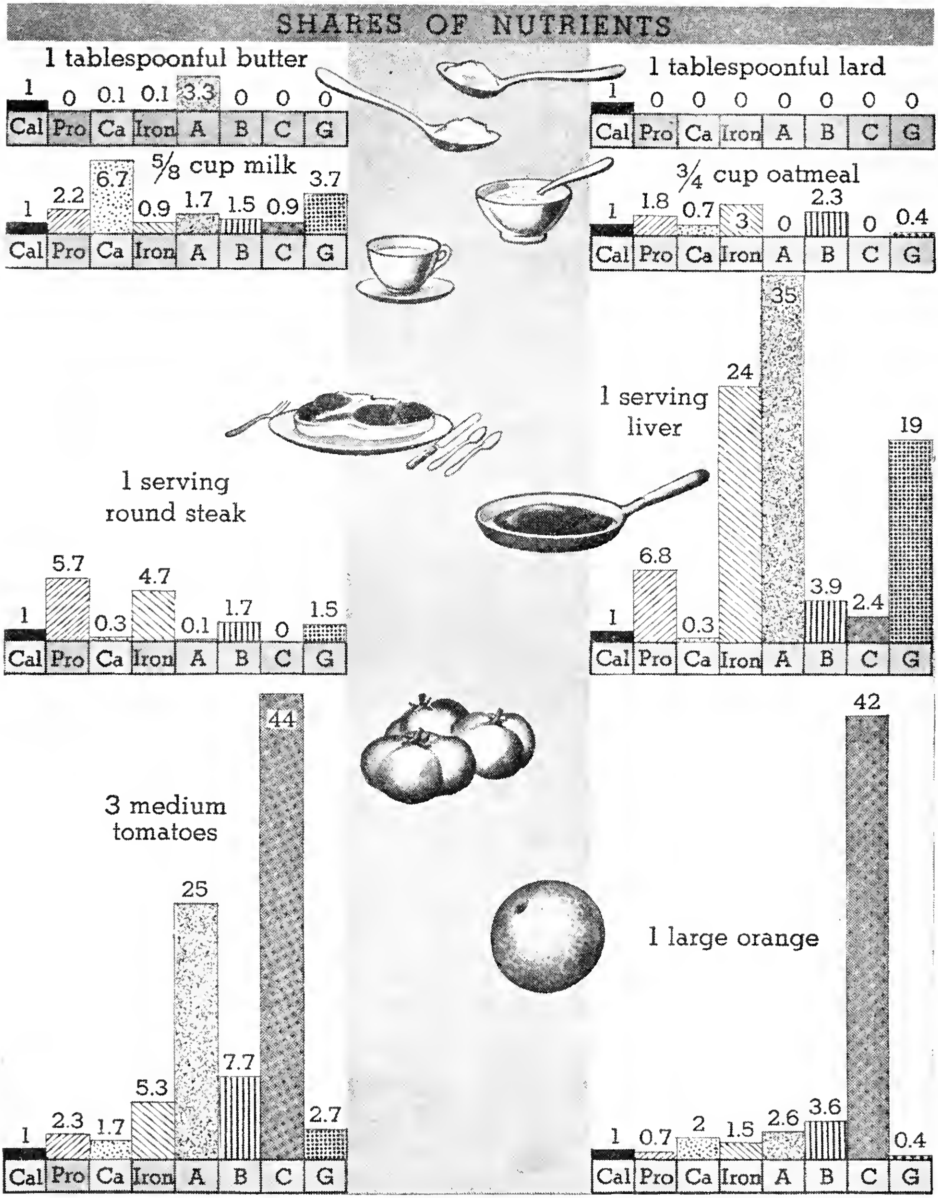
Enriched Flour For many years the grinding of wheat into flour has included the removal of the bran and parts of the germ, or embryo, of the grain. The bran is removed because people seem to prefer the pure white flour, and the germ is removed because that makes it possible to keep the flour from spoiling as it is shipped to all parts of the world or stored indefinitely. But as a result of such superior grinding the flour lacks certain components that are essential for the nutrition of those for whom flour bread is a large part of the diet. In 1942 the Food and Drug Administration ordered that all white flour used for baking bread be "enriched" with various vitamins and minerals.

Within a year after this order went into effect, a large New York hospital reported that beriberi and pellagra cases in its wards had declined by more than half. The legality of the order had been challenged, but the Supreme Court of the United States upheld the Administration in its authority to make the requirements in the interests of public health. Since October 1, 1943, the millers rather than the bakers must make the addition of vitamins

[1]The energy value of nutrients within the body is as follows:

	CALORIES PER GRAM
Proteins	4
Carbohydrates	4
Fats	9

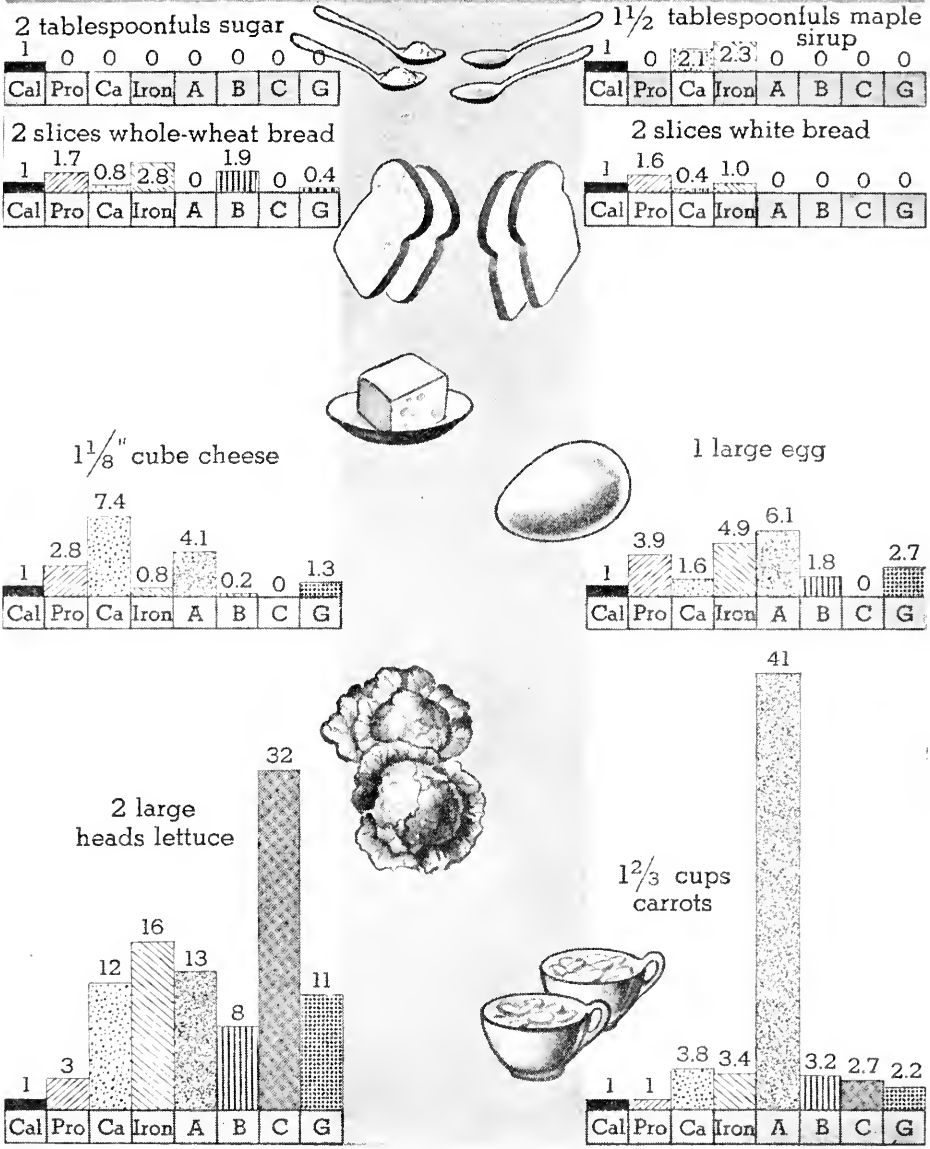
A given quantity of fat furnishes more than twice as much energy as the same quantity of proteins or carbohydrates.



COMPARING FOODS

For one who needs 2500 calories a day, twenty-five shares of any of the foods shown on these two pages would supply fuel for a day's work. We should not be satisfied with a diet of lettuce only, or even of oranges or steak. If one tried to live on eggs alone, the excess of protein would put extra work on the liver and kidneys,

IN 100-CALORIE PORTIONS OF FOODS



FOR BUILDING DIETS

and the extra vitamins A and G would not make up for the lack of vitamin C. All kinds of food are "good" for us, but no kind of food is suitable as an exclusive diet. Even milk, which comes nearest to a balanced food for human beings, would have to be supplemented with a few shares of iron and vitamin C

and minerals to all white flour. Now all white flour must have not more than 15 per cent moisture, and each pound should contain

NOT LESS THAN		NOT MORE THAN
2.0 milligrams	Vitamin B_1 (thiamin chloride)	2.5 milligrams
1.2 milligrams	Riboflavin (vitamin G)	1.5 milligrams
16.0 milligrams	Nicotinic acid (niacin)	20.0 milligrams
13.0 milligrams	Iron (Fe)	16.5 milligrams

The addition of vitamin D and calcium is optional; the maximum of calcium allowed is 625 milligrams per pound.

Schemes and Rules We can plan a diet by selecting items from each of these groups of foods. Thus Sherman gives two simple rules for selecting Calories, proteins, and the like in terms of food classes:

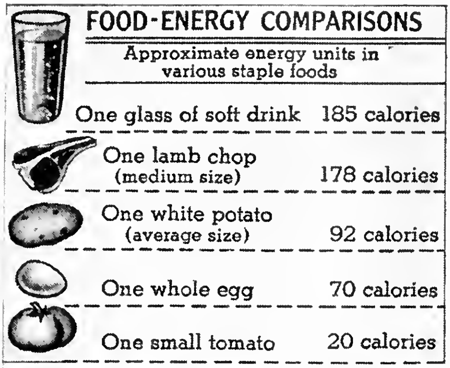
1. Let at least half the needed food calories be taken in the form of the "protective" foods—milk and its products, fruits, vegetables and eggs.
2. Whatever breadstuffs and other cereal or grain products are eaten, let at least half be in the "whole grain" or "dark" or "unskinned" forms.

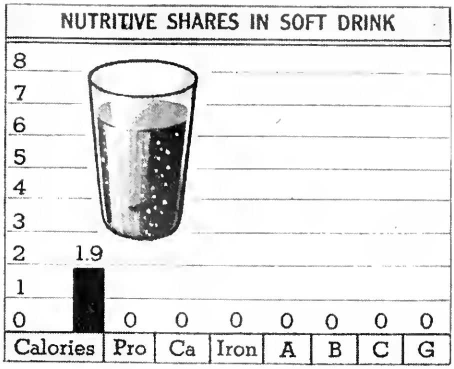
Sherman also recommends two arbitrary rules to follow in purchasing food. "Whatever the level of expenditure, it seems wise that (1) at least as much should be spent for milk (including cream and cheese if used) as for meats, poultry and fish; and (2) at least as much should be spent for fruit and vegetables as for meats, poultry, and fish."

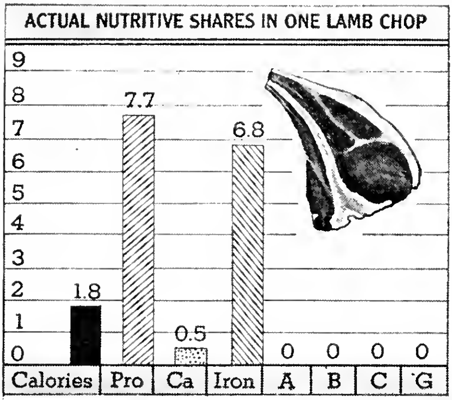
A simple way to use the results of some of the findings in nutrition research is to select food articles in wide variety from each of the seven classes listed above. This plan is likely to supply the needed minerals as well as the necessary vitamins, and it is likely also to satisfy the palate.

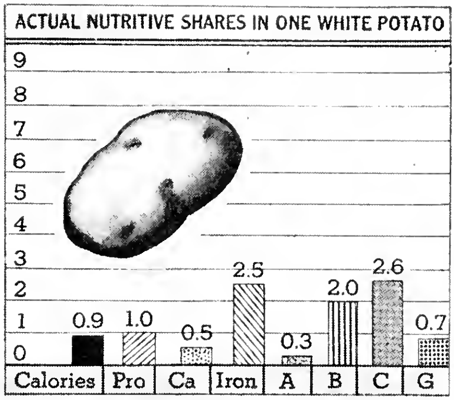
Share Technique A very useful scheme for the easy planning of balanced diets, the so-called "share" technique, was worked out by the late Mary Swartz Rose. Rose defined a *share* as that quantity of any food essential which supplies one thirtieth of the daily requirement of an adult using *3000 Calories* per day. Accordingly, one share of energy is equivalent to 100 Calories, one share of protein to 2.33 grams, and so on. The share values of the different food essentials and the recommended daily allowances of each shown in the table on page 130 differ but little from the original recommendations of Rose.

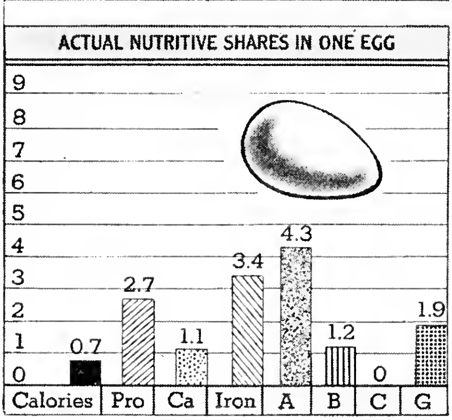
Not all the known dietary factors are included in the table on page 130. For example, one cannot plan his shares of vitamin D, since some of this factor is obtained in one's food while some of it is built up by the body; the quantity synthesized depends upon the amount of sunshine one gets. According to present knowledge, if one gets enough "shares" of energy, protein, calcium, iron, vitamin A, thiamin, ascorbic acid and riboflavin from

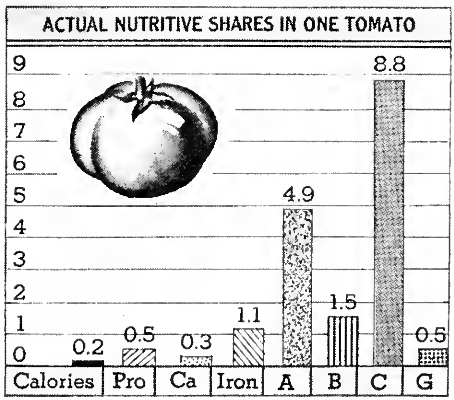












COMPARING FOOD VALUES

A large glass of sweetened and flavored water—a "soft drink"—can yield more "food energy" than almost any helping of good food you might choose in a restaurant. But it furnishes nothing at all of other food values, whereas each of the ordinary foods with which the soft drink is compared supplies essential proteins, minerals and vitamins. We can measure human energy in calories, but the body can release energy only if it is supplied with the other nutrients in suitable amounts

Share Values and Daily Requirements of Different Food Nutrients[1]

KIND OF NUTRIENT	QUANTITY OF NUTRIENT IN ONE SHARE	TOTAL DAILY REQUIREMENT OF MODERATELY ACTIVE MAN OF AVERAGE SIZE (154 LB.)	
		In Shares	In Other Units
Energy	*100 Cal*	30	*3000 Cal*
Protein	2.33 g	30	70 g
Calcium	27 mg	30	0.8 g
Iron	0.4 mg	30	12 mg
Vitamin A	167 international units	30	5000 international units
Thiamin (vitamin B)	0.06 mg	30	1.8 mg (600 international units)
Ascorbic acid (vitamin C)	2.5 mg	30	75 mg (1500 international units) (1500 U. S. P. units)
Riboflavin (vitamin G)	0.09 mg	30	2.7 mg
Niacin[2]	0.6 mg	30	18 mg

[1]These values are based on the Recommended Daily Allowances for Specific Nutrients suggested by the Committee on Foods and Nutrition of the National Research Council in May, 1941.
[2]The fact that there have been too few analyses of the niacin content of food makes it impracticable to calculate "shares" of niacin.

natural foods, he will also get sufficient supplies of phosphorus, niacin and all the other essential nutrients.

Requirements in Shares No single food furnishes a balanced diet. That is, nothing we eat has exactly the proportions of fuel, protein, calcium, and so on that are listed for one "share". If we analyze various foods and calculate what they actually contain in proportion to 100 Calories of energy, we find that most of the other essentials are present either in much larger or much smaller ratios than 1.0. We can see this at a glance in the table on the opposite page. All the food we eat yields energy—except water, minerals and vitamins. Conversely, various essentials are obtained with most of the energy foods, unless one is restricted to pure sugars and fats. But to get an adequate diet it is necessary to take a variety of foods.

By comparing various foods, we discover that some yield one essential in relatively large proportions, whereas others are rather restricted in their offerings. It is easy to make a great ado about a particular dish or preparation being exceptionally rich in a particular vitamin or in "quick energy", and to overlook everything else it lacks (see illustration, p. 129).

For most people a variety of foods selected in share units according to the total energy requirements will supply all needs. Growing children need a greater number of "shares" of protein, calcium, iron, vitamin A, and ascorbic acid in proportion to their "shares" of energy than do adults. Also special circumstances (such as the need for a reducing diet) or special conditions (such as pregnancy and lactation) require that the relative number

Nutritive Values of Foods in Shares[1]

FOOD	MEASURE	CALORIES	PROTEIN	CALCIUM	IRON	VITAMIN A	THIAMIN (B)	ASCORBIC ACID (C)	RIBOFLAVIN (G)
Cereals									
White bread (see p. 125)	2 slices	1.0	1.6	0.4	1.0	—	—	—	—
Whole-wheat bread	1⅓ slices	1.0	1.7	0.8	2.8	+	1.9	—	0.4
Rolled oats, cooked	¾ cup	1.0	1.8	0.7	3.0	—	2.3	—	0.4
Shredded wheat	1 biscuit	1.0	1.4	0.4	3.1	—	1.4	—	0.3
Milk and Cheese									
American cheese	1⅛-in. cube	1.0	2.8	7.4	0.8	4.1	0.2	—	1.3
Cottage cheese	5 tbsp	1.0	8.2	2.8	0.2	0.4	+	—	3.0
Whole milk, pasteurized	⅝ cup	1.0	2.2	6.7	0.9	1.7	1.5	0.9	3.7
Fruits and Vegetables									
Apples	1 large	1.0	0.2	0.5	1.4	0.6	1.1	4.0	0.5
Bananas	1 medium	1.0	0.6	0.3	1.6	1.7	1.3	3.2	0.7
Lima beans, fresh, steamed	½ cup	1.0	2.6	0.9	4.9	2.4	2.0	4.8	2.3
Carrots, fresh, steamed	1⅔ cups	1.0	1.0	3.8	3.4	40.8	3.2	2.7	2.2
Lettuce	2 large heads	1.0	3.0	12.0	16.0	13.0	8.0	32.0	11.0
Oranges	1 large	1.0	0.7	2.0	1.5	2.6	3.6	42.0	0.4
Peas, fresh, steamed	¾ cup	1.0	2.8	0.9	4.9	6.6	7.9	3.9	2.4
Potatoes, white	1 medium	1.0	1.1	0.5	2.8	0.3	1.0	1.0	0.8
Raisins, seedless	2⅓ tbsp	1.0	0.3	0.7	2.5	0.1	0.8	—	0.5
Spinach, chopped, steamed	2½ cups	1.0	3.5	*	26.5	500.0	5.5	28.0	16.0
Tomatoes, fresh	3 medium	1.0	2.3	1.7	5.3	24.7	7.7	44.0	2.7
Fats									
Butter	1 tbsp	1.0	—	0.1	0.1	3.3	—	—	—
Oleomargarine with vitamin A added	1 tbsp	1.0	0.1	0.1	0.2	3.3	—	—	—
Lard	1 tbsp	1.0	—	—	—	—	—	—	—
Salad oil, corn, cottonseed, olive	1 tbsp	1.0	—	—	—	—	—	—	—
Sugars									
Brown sugar	3 tbsp	1.0	—	0.9	1.8	—	—	—	—
Granulated sugar	2 tbsp	1.0	—	—	—	—	—	—	—
Loaf sugar	4 pieces	1.0	—	—	—	—	—	—	—
Maple sirup	1½ tbsp	1.0	—	2.1	2.7	—	—	—	—
Meats and Eggs									
Beef, round	avg serving	1.0	5.7	0.3	4.7	0.1	1.7	—	1.5
Eggs	1 large	1.0	3.9	1.6	4.9	6.1	1.8	—	2.7
Fish, mackerel	avg serving	1.0	5.8	0.3	1.6	0.8	1.1	—	5.4
Liver, fried	avg serving	1.0	6.8	0.3	23.6	35.0	3.9	2.4	19.1
Pork chop, broiled	½ chop	1.0	3.4	0.2	3.0	—	3.4	—	0.8

+Vitamin is present. —Not present in appreciable amounts. *Calcium not available.

[1]Adapted from Clara Mae Taylor, *Food Values in Shares and Weights*, 1942, pp. 8–41. By permission of The Macmillan Company, publishers.

VITAMIN			STABILITY	STORAGE IN BODY	RICH FOOD SOURCES
A	FAT-SOLUBLE	Derivative of carotin, the yellow color of carrots. Body forms it from carotin. $C_{20}H_{29}OH$	Is not easily destroyed at cooking temperatures. Is stable in acids and alkalies. Is slowly destroyed on exposure to air	Is stored to a considerable extent, especially in the liver	Milk and milk products, especially butter and cream, eggs, fish-liver oils, liver, yellow vegetables, and green leafy vegetables
D		Is formed from ergosterol, a plant fat, when it is exposed to ultra-violet light. Is formed in human skin when exposed to direct sunlight. $C_{27}H_{43}OH$	Is stable to heat, acids and alkalies, but deteriorates slowly	Is stored in skin, brain, thymus, adrenals, liver and kidneys	Fish-liver oils, sparingly present in ordinary food. Found in egg yolk, milk and butter. Less is found in milk products in winter than in summer. Small amounts are found in meat and fish
Tocopherol (E)		Tocopherol is made synthetically; is also obtained from the germ oil of wheat and other grains. $C_{29}H_{50}O_2$	Resists heat and oxidation, though decomposes when exposed to ultra-violet light	Is amply stored in the body	Is widely distributed. Is in all dairy products, in the oil of the germ of wheat and other grains; in eggs and green vegetables. (Is not found in fish oils)
Phylloquinone (K)		Two forms occur naturally, and related synthetic products have similar effect. Is lacking in body when there is a deficiency of bile; is synthesized by bacteria living in intestine. $C_{31}H_{46}O_2$	Is relatively stable; withstands heat	Is stored to a limited extent in liver	Widely distributed in foods. Concentrated form is prepared from fish meal or alfalfa
Ascorbic Acid (C)	WATER-SOLUBLE	Ascorbic acid is synthesized in pure state from glucose. Some mammals form this vitamin; man, monkey and guinea pig do not. $C_6H_8O_6$	Is easily destroyed by heat, especially in presence of alkalies. It also oxidizes readily in the air	Is not stored in body to any appreciable extent	Tomatoes and citrus fruits are especially rich sources. Other fruits, leafy vegetables, and germinating seeds are also good sources
Thiamin (B_1)		Is formed by certain bacteria, fungi and yeasts. Has been extracted in pure state from rice "polishings". $C_{12}H_{16}N_3Cl_2OS$	Withstands ordinary cooking but is easily destroyed in presence of a little soda. Lost if cooking waters are discarded	Is not stored to any extent in animal tissues; liver has slight amount	Germs of seeds, whole-grain cereals, nuts, tomatoes, spinach and peas are good sources. Liver and heart tissue are fair sources
Riboflavin (G)		Riboflavin has been isolated from milk, eggs, yeast and other sources. $C_{17}H_{20}N_4O_6$	Is generally stable; withstands heat	Is stored in body tissues, especially in liver	Liver, meat and fish, milk, eggs, green vegetables, tomatoes and yeast
Niacin		Niacin (nicotinic acid) is made synthetically as well as by green plants and yeast. $C_6H_5O_2N$	Is relatively stable; withstands heat	Is stored to a limited amount in lean meat and in liver	Liver, lean meat, fish, milk, eggs, peanuts, green vegetables, tomatoes and yeast

REGULATIVE EFFECT	EFFECT OF DEFICIENCY
Affects metabolism and growth; is essential in epithelial tissues and in vision	Deficiency results in lesions in nerve tissue and in mucous linings of respiratory tract, of alimentary canal, of reproductive and excretory organs, of the eye, and in various glands within the body. Deficiency results in night blindness. Though this vitamin is not specifically anti-infective, a lack of it results in damaged tissue, which increases likelihood of infection
Is essential in the absorption of calcium and phosphorus from the intestine and in their metabolism within the body	Lack of this vitamin results in poor bones and teeth. Extreme deficiency results in rickets, a deformed condition of the bones. In this sense it is called antirachitic
Is essential in the formation of placenta in female rats and other rodents	Lack of it causes embryos to die and males to become sterile. No conclusive evidence is at hand as to the necessity of this vitamin in human reproduction. Is called antisterility factor
Is essential for formation of prothrombin, an important coagulating constituent of the blood	When deficient, blood will not clot. Hence called antihemorrhagic, although hemorrhages are initiated by conditions other than the "absence" of phylloquinone
Is essential for the normal development and maintenance of bones, teeth, capillary walls, gums and joints. Is essential in normal growth	Inadequate supply results in irritability, lack of stamina, retardation of growth, fragile bones, weakened capillaries, and pains in joints. Extreme deficiency results in hemorrhages in various organs, discolored areas under skin, tenderness and swelling of joints, swollen and bleeding gums, and loosening of teeth in sockets, all characteristic symptoms of scurvy. Is called antiscorbutic
Influences appetite, digestion, particularly motility of intestine, growth, and nervous system. Is essential in carbohydrate metabolism	Slight deficiency results in loss of appetite, sluggishness of stomach and intestine, nervousness and irritability. Extreme deficiency interferes with nerves, resulting in a paralysis of the limbs, a condition called beriberi in humans and polyneuritis in other animals. Is called antineuritic
Combines with phosphoric acid and protein, forming respiratory enzymes. Is essential for normal health at any age	Deficiency results in digestive disturbances, nervousness, weakness, unhealthy skin. Mouth lesions occur at the junction of the mucous membrane and skin around the mouth. Characteristic lesions appear in the cornea
Essential in formation of respiratory enzymes. Is needed for normal health and growth, especially in skin and gastrointestinal tissues	Deficiency results in a disease called *pellagra*, in which the patient has an inflamed skin, is nervously depressed, and may develop an inflamed tongue and mouth lining and a severe disorder of the digestive tract. The dermatitis usually occurs symmetrically on the body as on the backs of the hands, on the forearms, or on the ankles. The typical pellagrin usually suffers from a lack of riboflavin and thiamin as well as niacin

of "shares" of energy be proportionately less than the number of "shares" of each of the other essential nutrients.

Shares in Foods[1] With this device of "shares" it is easy to plot an individual's total needs and to plan to meet those needs with shares of food. The table on page 131 shows the contributions of common foods to the diet in relation to their energy value. Note that in many cases a share of energy corresponds roughly to a serving we commonly take. By representing with bar graphs the shares of each of these dietary essentials, one can quickly visualize which foods are rich in energy, or mineral, or ascorbic acid, and so on (see pages 126, 127).

Lettuce, spinach, and other fresh vegetables and fruits contain a high percentage of water; they therefore yield relatively little energy per pound. On the other hand, butter and other fats are extremely rich sources of energy (see footnote, p. 125). Sugar, candy, and other sweets yield much energy and little else. Milk, cheese, meat, fish, eggs, peas and beans are rich sources of proteins. The mineral content of milk, cheese, eggs, and various fruits and vegetables is high. Some foods are rich in one vitamin and poor in other vitamins. In general, milk, eggs, liver, and various fruits and vegetables are high in vitamin content. The foods arbitrarily listed in the table, p. 131, illustrate the shares present in different kinds of foods.

In Brief

The basic needs of the body vary primarily with the rate of growth and with the amount of heat lost from the body surface.

Above minimum, or basic, energy expenditure the activities determine the energy required by an individual from hour to hour.

The energy expenditures of the body are measured in heat units, Calories, by various types of calorimeters.

The basal metabolism of a person is his rate of energy expenditure when he is awake, relaxed and lying still, at least twelve hours after the last meal.

Because children vary in size, in rates of growth, and in activity, their energy requirements at any given age vary widely.

The total energy requirement of a day-laborer doing heavy work is approximately twice that of a similar person engaged in clerical work.

One can continue for a long time on a deficient diet without realizing it, but in the meantime injuries accumulate. It is therefore important to acquire tastes and practices guided by reliable knowledge of food needs.

Milk and milk products, eggs, and fruits and vegetables are considered "protective" foods because of the minerals and vitamins they contain.

[1]See No. 6, p. 136.

Diets can be planned to meet daily needs by using the "share" technique. A share of any food-essential is that quantity which supplies one thirtieth of the daily needs for an adult using 3000 Calories per day. Thus a share of energy is equivalent to 100 Calories.

EXPLORATIONS AND PROJECTS

1 To measure the rate at which a person spends energy, find out how much oxygen he uses in a given time. Where a basal-metabolism apparatus is not accessible, it is possible to construct one patterned after Benedict's Student Respiration Apparatus.[1] The subject (sitting or lying quietly) holds the mouthpiece in mouth while breathing through the nose. Attach oxygen tank to air inlet and fill inside of apparatus with oxygen. Remove hose from oxygen tank and connect pump.[2]

When everything is in readiness have the subject start breathing through his mouth. Place nose-clip on his nose. Count the time from the first exhalation that fails to make the rubber cap touch the stop wire. The starting time can be hastened by adjusting the amount of air inside the apparatus with the pump, immediately after the subject starts breathing from it. As the test proceeds, keep the volume of gas constant within the apparatus by pumping in air to replace oxygen used by the subject. Oxygen used by the subject is measured by the quantity of air pumped in to replace the oxygen consumed. The carbon dioxide breathed out by the subject is absorbed by the soda-lime. Tests should be run from five to ten minutes.

From the number of cubic centimeters of oxygen used and the duration of the test, calculate the amount of energy the subject would spend in a day if he used energy continuously at the same rate.[3] Record the observations and make the calculations in table form.[4] (Do not write in this book.)

2 To calculate your own basal expenditure of energy per day, use the table on page 121.

[1]See illustration, p. 120. The material, with the exception of the rubber gas-mask valves, rubber bathing cap, and the soda-lime, can be picked up locally. This apparatus is just as satisfactory for classroom measurements as the more expensive purchased ones. (Respiration apparatus and accessories may be obtained from Warren E. Collins, 555 Huntington Ave., Boston, Mass.)

[2]The pump can be calibrated by measuring the volume of water that each pumpful of air displaces from a graduated cylinder inverted over a water bath.

[3]Assume .004825 Calorie for each cubic centimeter of oxygen used.

[4]Figures for column IV are obtained by multiplying the number of pumpfuls (III) by the volume of the pump in cubic centimeters. Figures for column VI are obtained by multiplying cubic centimeters per minute (column V) by 1440, the number of minutes per day.

I	II	III	IV	V	VI	VII	VIII	IX
Name of Subject	Duration of Test in Minutes	No. of Pumpfuls of Oxygen Used	Cubic Centimeters Used during Test	Cubic Centimeters Used per Minute	Cubic Centimeters Used per Day	Calories Used per Day	Body-Weight in Pounds	Calories Used per Day per Pound of Body-Weight

3 To show that activity increases the rate of energy expenditure, compare the person's oxygen consumption at rest and while active. Make a respiration test as described in No. 1 above. As soon as the test has been started, have subject raise and lower kilogram weights in each hand for remainder of the time. Compare rate of oxygen consumption, or expenditure of energy, when subject is exercising and when sitting still; compare additional energy expenditure of several working at different rates.

4 To determine the percentage of water in various foods, remove the water from each of several kinds of food by heating weighed quantities at 100° C for several hours and weighing what is left. From these figures calculate the percentage of water in each food. Use 100-Calorie portions of each so that you can compare the relation of water content to energy value.

5 To determine the amount of mineral matter in these same foods, burn out the organic portion of each and weigh the ash that is left.

6 To compare the contributions of different foods to the diet, make bar graphs representing the "shares" in the foods listed in the table on page 131. For comparative purposes, all the bar graphs should be made on the same scale. Use $\frac{1}{4}$-inch graph paper and allow three squares for each share of each nutrient. Use a distinct color or shading for each nutrient.

QUESTIONS

1 What connection is there between muscle activity and breathing? between muscle activity and heartbeat? between muscle activity and exertion?

2 How can one overeat and at the same time be malnourished?

3 What factors influence the basic needs of the body?

4 What determines the energy required by an individual beyond the basic expenditure of energy?

5 What factors determine the wide variations in the energy requirements of children at different ages?

6 How far can we trust our feelings in deciding what and how much to eat?

7 How is it that energy expenditure can be measured in terms of the amount of oxygen consumed?

8 In what sense are certain foods "protective" foods?

9 How can we classify foods according to what they furnish in our diet?

10 How can we use the "share" technique in planning our diet?

11 Which vitamins are water-soluble? fat-soluble?

12 Which vitamins are most stable? least stable?

13 Which vitamins are generally stored within the body? which are not so stored?

14 What are the regulative effects of each of the vitamins?

15 What dysfunctions result from a deficiency of each of the vitamins?

16 How can one make sure that vitamin values are not lost in cooking?

CHAPTER 8 · HOW DO FOOD STUFFS COME INTO BEING?

1 How do new supplies of organic material originate?
2 Could all living things make their own food if there were no others from whom they could take it?
3 Is it true that plants breathe in what animals breathe out, and that animals breathe in what plants breathe out?
4 Can plants live without roots?
5 Where does the carbon in foods come from?
6 Where does the nitrogen in foods come from?
7 Why is it necessary to buy nitrogenous fertilizers when there is so much nitrogen in the air?
8 Is soil important now that we can grow plants without it?
9 Why do farmers prefer valley lands to upland farms?
10 Is there danger of exhausting our soil resources?

When proteins, fats, and carbohydrates become assimilated into the protoplasm of any plant or animal, they are still available as food for other living beings. But when any of this material becomes oxidized, it is thrown out of the world of living things. Now living matter can continue to live only at the expense of other living matter, and living matter is constantly being destroyed (oxidized). How, then, can the total amount of protoplasm increase, or even remain the same? The answer to this question was found in the discovery that the green parts of plants create new organic foods out of inorganic materials. But how can green plants make new organic foods when other living things cannot do so? Out of what do plants make these foods?

How Is Organic Material Made Anew?

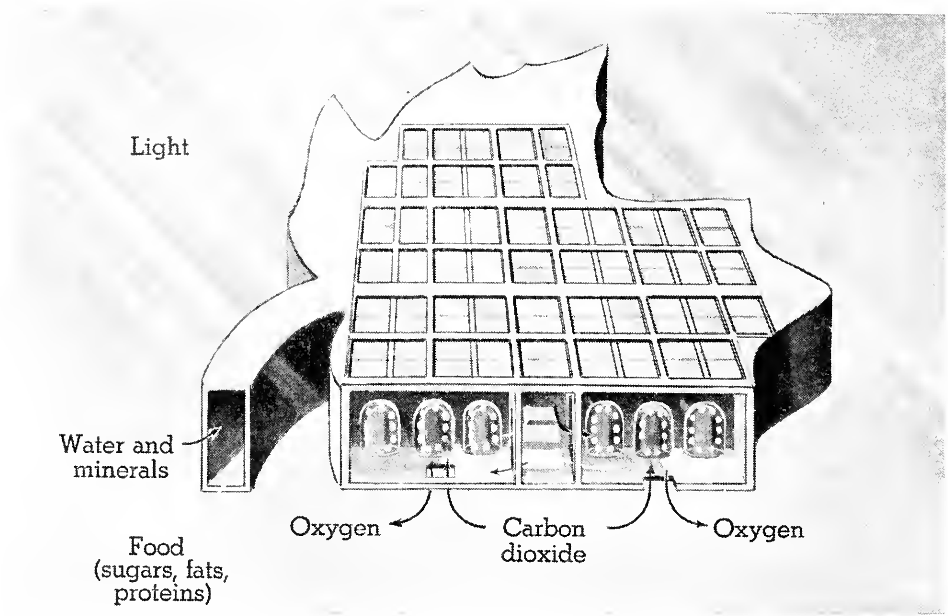
A Manufacturing Process[1] The making of organic substances out of inorganic materials may be compared to a manufacturing process. In every such process there must be (1) raw material, (2) tools or machines that work on the material, and (3) energy to drive the tools or machines. There is of course (4) a main product, and sometimes there are (5) left-over wastes, or *by-products.*

The simplest organic product that we can recognize in a plant is a sugar.

The raw materials used by the plant in making carbohydrates, or sugars, are *water* and carbon dioxide.

The plant's machines or instruments differ from those with which we are familiar and which consist of wheels and levers or other moving parts.

[1]See Nos. 1–4, pp. 157–158.



THE LEAF AS A MANUFACTURING PLANT

The plant uses *chemical engines*, each consisting of a lump of protein with some of the pigment that gives familiar plants their distinctive color. This substance is called *chlorophyl* (from the Greek *chloros*, "green", and *phyllon*, "leaf"). Chlorophyl is the actual transformer of energy in the food-making process (see illustration above).

The energy for doing this work is the light from the sun. Although the work cannot go on at too low a temperature, it is radiant energy, *light*, that is active, not *heat*.

The sugar formed by the action of sunlight upon chlorophyl consists of the elements carbon, hydrogen and oxygen, which are derived from raw material, water (H_2O) and carbon dioxide (CO_2).

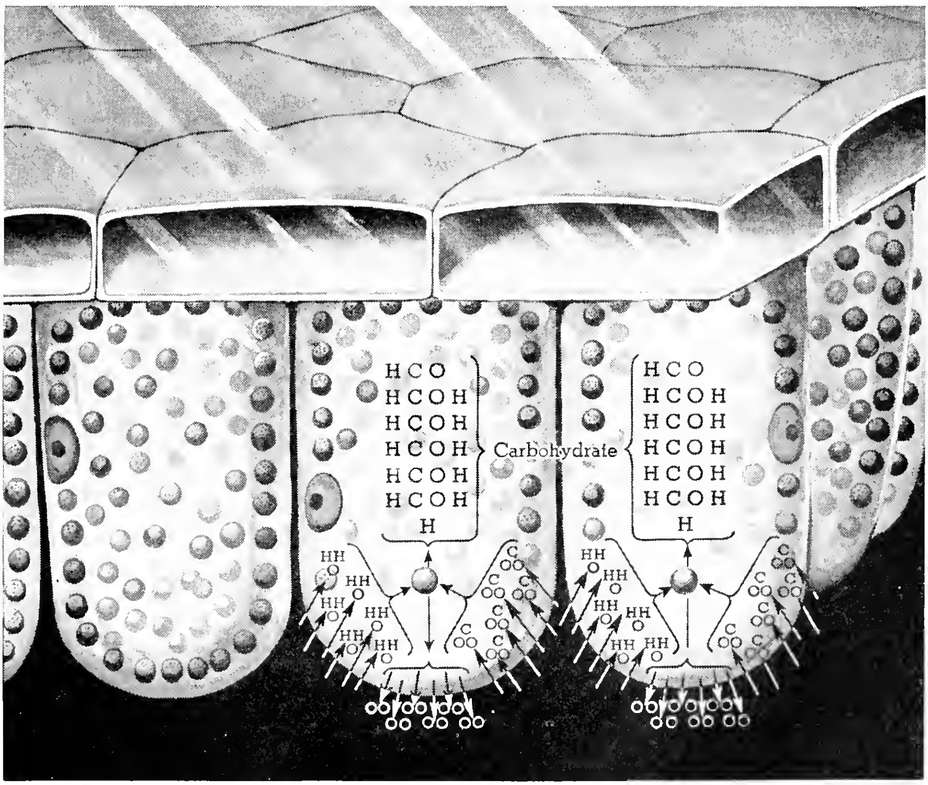
Sunlight and Life In the presence of light and chlorophyl the elements of carbon dioxide and water recombine, forming sugar and liberating oxygen. The action may be represented thus:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

We may read this formula thus: six molecules of carbon dioxide plus six molecules of water (under the action of sunlight) form one molecule of sugar and six molecules of oxygen (see illustration, p. 139). Energy equivalent to that absorbed from the sunlight is present as latent or "fuel" energy in the carbohydrate.

The process of carbohydrate formation by chlorophyl is called *photosynthesis*, from two Greek words meaning "light" (compare *photo*graph) and "a putting together". It is easy to show that in the absence of light, chlorophyl is inactive and photosynthesis is suspended. Moreover, if a plant is kept in darkness for a longer period, the chlorophyl begins to disappear, and in the end the leaves will turn yellow or even white. We use this fact in the blanching of celery. We also know that the outer, exposed, leaves of a head of lettuce or cabbage are much greener than the inner leaves.

Experiments have shown that plants can carry on this work under artificial light. By the use of strong electric light during the night, lettuce plants have been hastened in their growth and development, and brought



PHOTOSYNTHESIS IN A LEAF

Palisade cells receive water from the roots by way of fine tubules, and carbon dioxide by osmosis from the surrounding air spaces. Under the action of sunlight, the chlorophyl combines carbon, oxygen and hydrogen from water and carbon dioxide into sugar or starch molecules, and an excess of oxygen passes out of the cells by osmosis

to market at least two weeks earlier. Some plants can apparently be kept working continuously, as they seem to need no "rest" or "sleep".

Leaves as Starch Factories Common plants carry on photosynthesis in a special organ, the leaf. The characteristic feature about leaves is the *blade*, or flat and comparatively thin structure. Some leaves have stalks, or petioles; and all have "veins" running through the blade. Leaves vary remarkably in size, shape and the character of the edges and of the surface (see illustration, p. 43). Some are hairy; others are quite bald. Even the color is not uniform, for the chlorophyl varies in density, and the appearance is influenced by other pigments, air spaces, wrinkles, hairs, and other details. And many "leaves" depart widely from our ordinary notion of what a leaf is. Some are hardly more than stiff bristles, as on certain cactuses. Others have sensitive extensions, or tendrils. In some species the leaves are more or less active in capturing animal food (see page 542). But starch-making proceeds in about the same way in all leaves containing chlorophyl (see illustration, p. 139).

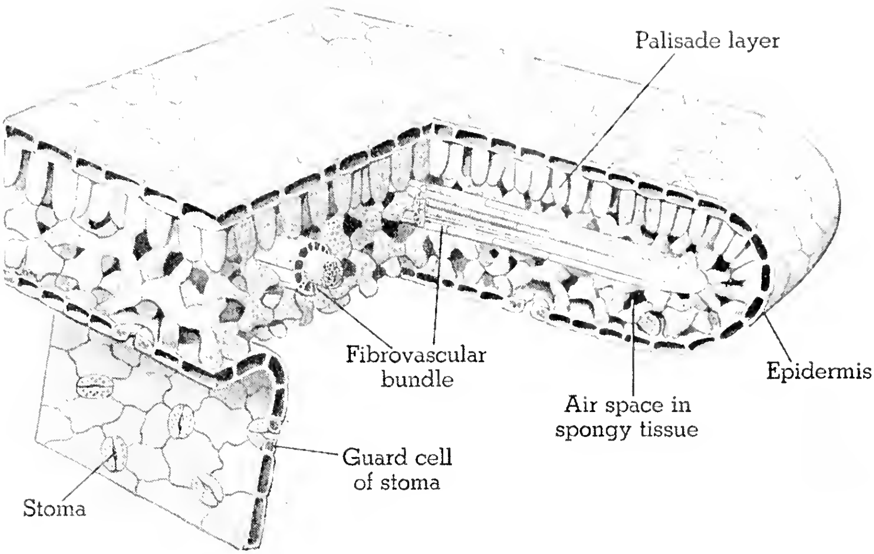
Transpiration[1] Water evaporating from the leaves sets up currents that distribute throughout the plant water and salts absorbed from the soil. This loss of water, or transpiration, is at the same time a source of danger to the plant, for more plants die from wilting than from any other one cause.

[1]See Nos. 5 and 6, p. 158.

L. P. Flory, Boyce Thompson Institute

LIGHT AND CHLOROPHYL

Normal seedlings grown in the light appear green from the start. Seedlings kept in the dark remain white until after they are placed in light. Albino plants never develop chlorophyl, and wither when the seed nutriment is exhausted



STRUCTURE OF LEAF

Vessels of the fibrovascular bundles, the air spaces among the cells, and the stomata in the epidermis act as channels through which the living cells inside the leaf communicate with lower parts of the plant and with the surrounding atmosphere

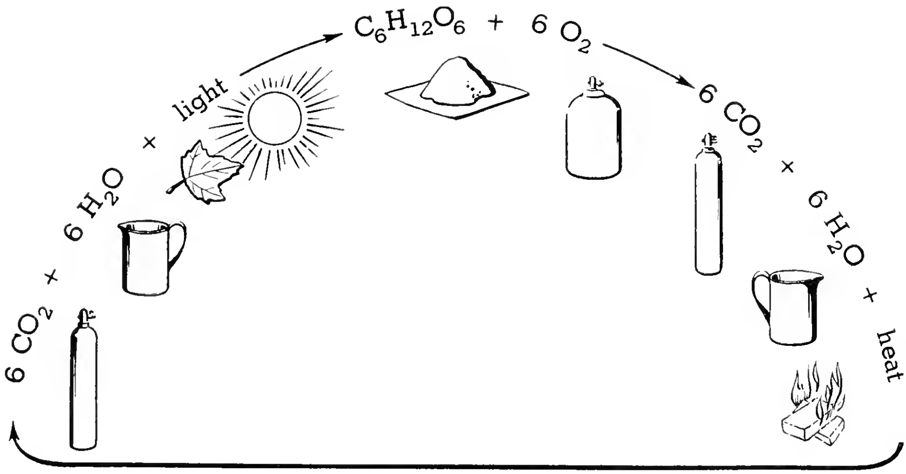
Transpiration may also be of use to the plant indirectly, for the rapid evaporation of water *lowers the temperature of the plant.* Sometimes in the summer the sun comes out quickly after a shower. Then the moisture left in the air may prevent transpiration, and as a result the sunlight is converted into heat inside the leaf so rapidly that the protoplasm is injured.

Both "breathing", or gas exchange, and transpiration appear to be regulated by the guard cells of the stomata (see illustration, p. 143).

Our Dependence upon Chlorophyl From careful chemical studies it appears that plant cells make proteins when they receive, in addition to carbohydrates, *salts* containing certain elements. Nitrates, for example, contain nitrogen; phosphates contain phosphorus; sulfates contain sulfur; and so on. A green plant can therefore produce its own food if it receives, in addition to the water and carbon dioxide, a suitable supply of minerals from the soil. Many plants without chlorophyl, such as molds and yeasts, are also able to make proteins when supplied with carbohydrates and suitable minerals. And we know that our own bodies as well as those of other animals and of plants can transform starches and sugars into fats.

The parts of a plant that have no chlorophyl (for example, the root or the stem of a tree) are unable to make food substances out of inorganic materials. They are nourished by materials obtained from the leaves. But

animals and such plants as mushrooms, which have no chlorophyl, must get their organic food from the bodies of other living things.



PHOTOSYNTHESIS AND RESPIRATION

When photosynthesis takes place, light energy is absorbed and stored. When sugar is oxidized, the stored energy is liberated as heat. The waste products of respiration are the raw materials of photosynthesis

In the end, all food comes from green plants. It is as if the carbon and the oxygen in CO_2 were pulled asunder by the action of sunlight through chlorophyl. They are then able to combine again and so liberate energy. It is thus that carbohydrates yield energy in becoming oxidized, whether in the body of a living thing or in a flame. All the energy which plants and animals get from the oxidation of carbohydrates, fats, or proteins is thus derived from the sun's energy. There is more than poetry in the statement that every human act is a transformed sunbeam.

How Do Minerals Reach the Leaves?

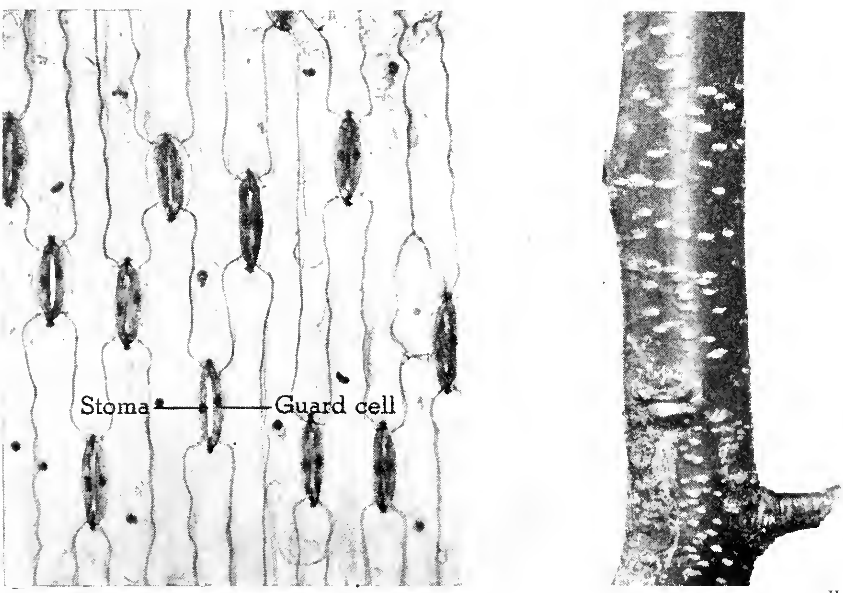
The Work of the Root[1] Roots are familiar to us as plant anchors. They are also special organs through which plants absorb water and dissolved minerals, and through which they get rid of wastes. The actual exchange of material between the plant and the soil takes place through the thin walls of the delicate root hair (see illustration, p. 144). As the plant grows larger, its absorbing area increases by the branching of the roots. But it is always in the regions near the growing tips of rootlets that root hairs are formed—and that absorption takes place.

[1]See No. 7, p. 158.

In roots of such plants as the carrot or parsnip we can distinguish an easily broken outer layer and a tougher core, or "central cylinder", running lengthwise. The two layers correspond respectively to the bark and the wood seen in the stem of a tree. With a microscope we can see that there are several different kinds of cells in the root (see illustration, p. 144). In the central cylinder the cells are much longer in proportion to their width than are those in the *cortex*, or bark; and their long diameters run lengthwise of the root.

Such fleshy roots illustrate a third function that many roots carry on, namely, that of "storing", or accumulating, surpluses of food material. But whether roots are fleshy or stringy or woody, they generally *absorb* and *transfer* materials.

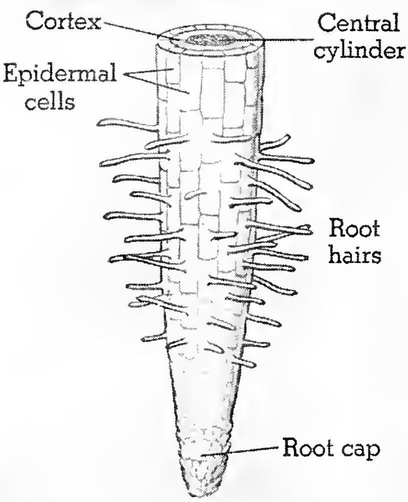
Vessels and Fibers In the cortex of a root, movement of material results from simple diffusion or osmosis from cell to cell. In the central cylinder, however, liquids move bodily through long tubes or vessels that act as main channels in the plant. There are, in fact, two sets of conducting tubes. Through the smaller vessels in the central cylinder food materials produced in the leaves are carried down toward the growing parts of the



Hugh Spencer

AIR HOLES OF PLANTS

Thin-walled "guard cells" enclose each stoma and carry on photosynthesis. When they are turgid, the stomata are open; when they become flaccid, the stomata are closed. Stomata occur in the epidermis of twigs, as well as on leaves. As the stem grows tougher, the holes become larger and more irregular. The roughened spaces on the bark are lenticels



Radish seedling

Hugh Spencer

THE TIP OF A YOUNG ROOT

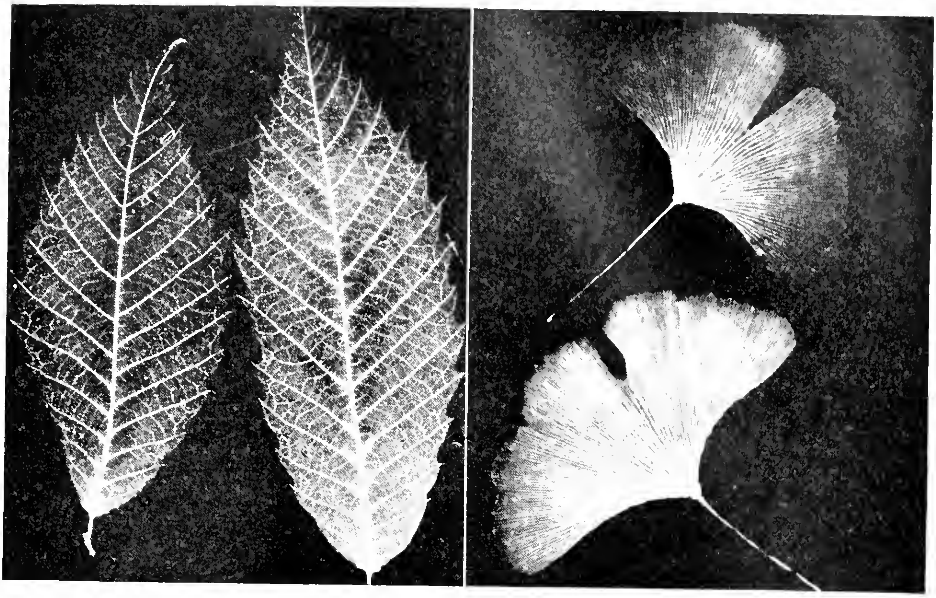
Each root hair is a single cell formed by the outward prolongation of one of the skin cells. Each root hair lives but a short time and then shrivels up. New root hairs are formed as the tip of the root continues to grow. The older skin cells of the root die and dry out, making a protective cover through which little water passes

root. The tubes through which water passes from the roots to the leaves are called *xylem*, or wood vessels; those through which organic foods pass downward from the leaves to all other parts of the plant are called *phloem*, or bast vessels.

Associated closely with the two kinds of ducts, or tube-cells, there are other elongated cells having rather thick walls of cellulose. These are the *fibers*, which are usually more tough and rigid than those we find in the carrot. The bundles of fibers and vessels together make up the "fibrovascular bundles", which are conspicuous in all our common plants above the rank of mosses and liverworts—that is, from the ferns onward (see Appendix A).

The fibrovascular bundles of the root are continuous with those of the leaf, by way of the stem. They branch and subdivide as the plant grows; and in the leaves we can see the bundles reaching to all parts as "veins" (see illustration opposite).

The fibers are most conspicuous in the stems of plants, which we readily recognize as mechanical supports. The wood of trees consists very largely of fibers, as do the tough parts of bark. We make extensive use not only of wood, but of the fibrovascular bundles of many plants in the form of



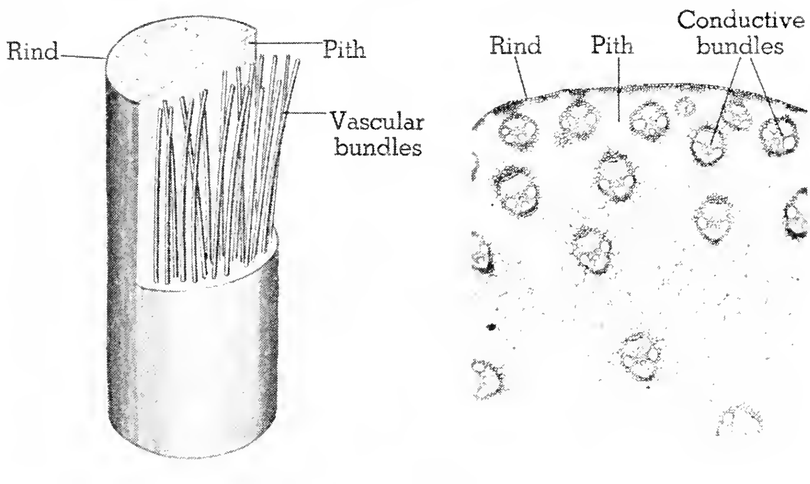
FIBROVASCULAR BUNDLES IN LEAVES

The living cells in the blade of the leaf receive water and dissolved minerals and send food through an intricate system of small veins, which extend to all regions of the leaf. These small veins, or fibrovascular bundles, connect with larger veins in the leaf, the stem and the roots

separate threads—for example, flax, hemp, sisal, linen, and so on. Children like to pull the "nerves" out of the leaves of plantain, and we are all familiar with the "nerves" in the celery stalk and with the strings in cornstalk.

The arrangements of fibrovascular bundles in stems and leaves are so characteristic that they enable us to recognize at once members of the two main divisions of seed-plants, namely, monocots and dicots (see Appendix A). In the monocots, plants having but one cotyledon in the seed, the veins run almost parallel, as in grasses, lilies and bananas. In the leaves of dicots, plants having two cotyledons in the seed, the veins run into each other, forming networks, as in the potato plant, the elm, or the geranium (see illustration above).

Types of Stems In monocotyledonous plants fibrovascular bundles are scattered throughout the stem (see illustration, p. 146). They are much more numerous toward the outside. The water-conducting vessels (xylem) are toward the center of the stem, and the food-conducting cells (phloem) are toward the outside. Between the xylem and phloem tubes and surrounding them are the thick-walled woody fibers.



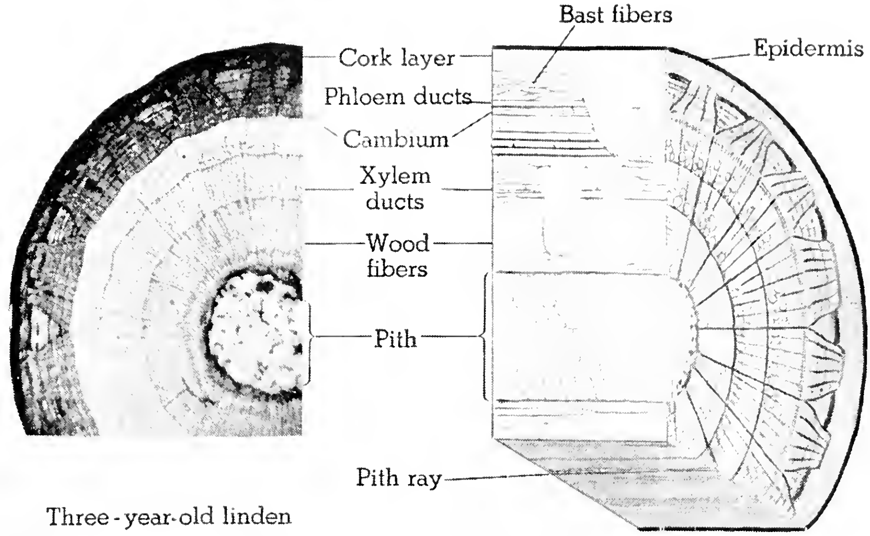
Right, © General Biological Supply House, Inc.

CONDUCTING TISSUES IN CORN STEM

The tough fibrovascular bundles of conducting cells are surrounded by tender pith cells; these can be readily shredded away and the bundles exposed. The arrangement of the bundles clustered toward the outer rind is analogous to the hollow-tube construction of a bicycle frame as a supporting structure

In dicotyledonous stems the fibrovascular bundles are arranged symmetrically around the center. As in the monocots, the xylem tubes are toward the center, and the phloem tubes are toward the outside. In the dicots, however, these two sets of vessels are separated by a layer of undifferentiated, growing cells. This layer is called the *cambium* layer. The new cells which the cambium produces toward the center become woody fibers and xylem tubes. Cells formed on the outer side of the cambium become bast fibers and phloem tubes. As the stem grows in thickness, the cambium layer is pushed away from the center. As the bark is pushed outward, the outermost layers split or peel in various ways. This results in the characteristic markings of various species, such as a birch tree or an oak, for example.

Circulation of Sap in Plants The rise of water to the tops of tall trees has always puzzled people. There was no systematic study of the problem before about 200 years ago, when Stephen Hales (1677–1761), an English preacher, first used mercury gauges to measure the pressure with which sap rises in plants. Hales came upon the idea of measuring the sap pressure when he tried to stop the "bleeding" of a vine. He tied a piece of bladder over the cut end, and then noticed that the bladder swelled up. He continued his experiments and showed that the root pressure, which we now recognize



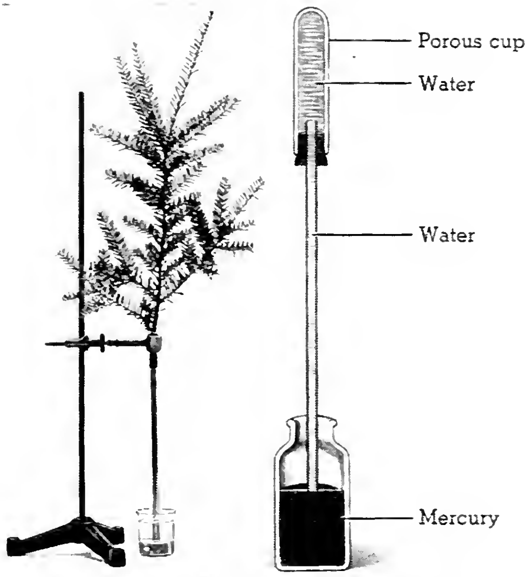
STRUCTURE OF A DICOT STEM

Growth in the cambium layer produces new woody tissue on the inside and new bark tissue, or cork, on the outside of this layer. During the spring, when growth is rapid, large xylem tubes are formed. Later, growth slows down, and a definite ring of denser tissue is formed. The number of annual rings in the woody part of the stem tells us the age of a tree. Food travels down the stem from the leaves through the phloem tubes; water and dissolved mineral salts travel up from the roots through the xylem tubes. Rays of pith cells connect the cambium with the xylem tubes

as due to osmosis, and transpiration were sufficient to explain the rise of sap (see illustration, p. 148).

The minute diameters of the xylem vessels probably also play a part in connection with osmosis and transpiration. No vessels reach the whole length of a plant, so that the "capillary" attraction can raise water but a short distance in each cell. Other experiments have shown that water is "pulled" through the xylem tubes as it evaporates from the cells of the leaves. This is explained by the fact that particles of water cohere, or cling together, when confined in the narrow tubes. The network of water-threads in the plant can carry a considerable amount of strain, equal to a pull to the top of the tallest trees.

Fluids in plants not only rise, but, as we have seen, move also from the leaves toward the roots. We can show that this part of the circulation is by way of the phloem vessels. If the bark is removed from a tree so as to leave a complete ring or "girdle" unprotected, the tree can continue to live for the rest of the season. This shows that the water continues to rise from



If we cut the stem of a living plant under cold water that has been boiled to remove the air, and then connect it with a glass tube while still under water, the vessels of the stem and leaves are in communication with the water in the tube. Now we may set the stem upright, with the lower end of the tube dipping into mercury. In this arrangement mercury rises in the tube as if the water were being pulled or pushed into the stem. With a porous cup full of water in place of the twig, the water and mercury behave in the same way. What becomes of the water that disappears out of the glass tube? How is the water actually raised?

Left: L. P. Flory, Boyce Thompson Institute

WATER RAISED BY TRANSPIRATION

the soil with its dissolved salts—but *not* in the bark or phloem vessels. The following spring, however, the buds will not open; the tree will be dead. This is because the water now coming from the roots is without organic food. The food reserves could not come down into the roots after the tree was girdled, for it is through the phloem vessels that organic food comes from the leaves to the lower parts of the plant.

Is There Danger of Exhausting the Supply of Raw Materials Used by Plants in Food Production?

The Carbon Cycle If we understand how green plants make food, we can see more clearly how the living things in the world depend upon each other. The carbon in our bodies, for example, came from the proteins, fats and carbohydrates which we ate. We obtained these either from the bodies of plants or from the bodies of animals. The cows or pigs or chickens that we used as food had in turn obtained the carbon in their bodies from the plant food which they had eaten.

Now the plant gets its carbon from the carbon dioxide in the air. But what is the source of this fraction of 1 per cent of the atmosphere? The plants in North America could use it all up in a few sunny August days—and that would be the end of everything. Certain rocks—limestone and marble especially—yield small quantities of this gas when they decompose.

But this amount is very small indeed when we consider what is being used up by plants from hour to hour. There is, however, still another source.

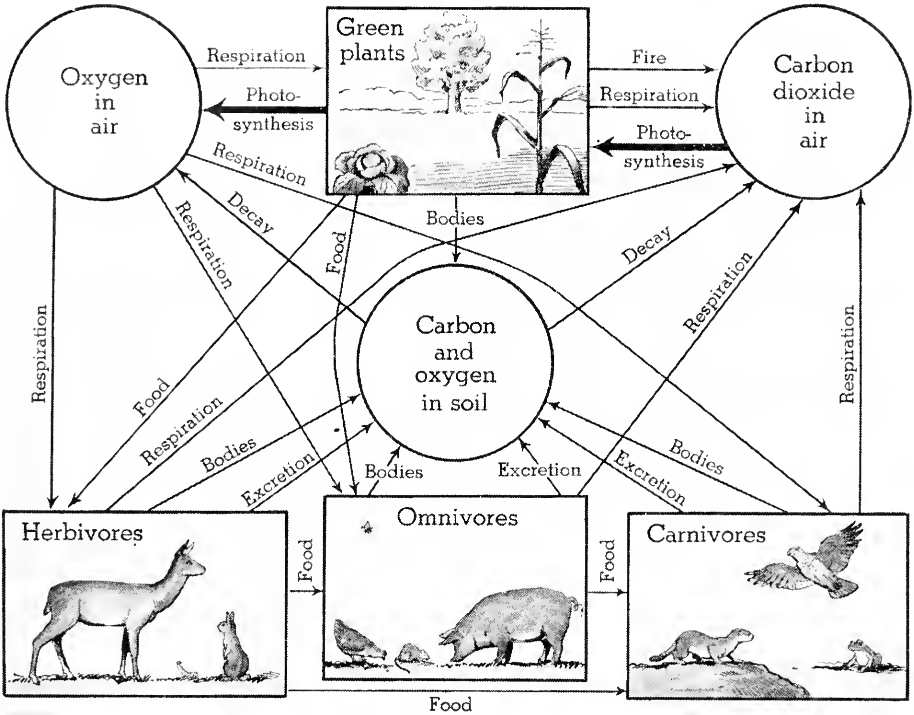
We have seen (see page 84) that all living things, while using oxygen from the air, are at the same time throwing off carbon dioxide. Moreover, every fire discharges quantities of carbon dioxide. This carbon dioxide in the air then becomes raw material for food in green plants. However, the amount of carbon dioxide that fires and animals can yield is limited by the quantity of plant life. For the only fuel available is the organic material which green plants manufactured in the first place.

We see, then, that our lives depend upon the green plants, and that, on the other hand, the growth of green plants depends upon the oxidation of organic substances in the bodies of animals or in fires. There is, thus, a certain balance between the total quantity of plant life in the world and the total quantity of animal life. If the amount of animal life should diminish very greatly, the growth of plants would in time be slowed or stopped by the lack of carbon dioxide. Should the amount of plant life decrease greatly, the growth of animals would soon reach a limit for lack of food (see illustration, p. 150).

The Oxygen Cycle Oxygen is the most abundant of the elements in the earth's crust; and the amount of oxygen in the atmosphere is very much greater than the amount of carbon dioxide. But it is a limited amount. Now all living things are constantly drawing upon this oxygen, for living includes the release of energy by the oxidation of food substances. After oxygen has taken part in the oxidation of organic material, it is no longer available for similar action. Through photosynthesis, oxygen is liberated, and thus becomes again available for the breathing of animals and plants. If all green plants should suddenly stop their activities, the amount of oxygen would as rapidly diminish. In a short time animal life would cease (see illustration, p. 150).

The Nitrogen Problem In the bodies of plants and animals proteins break down into simpler compounds of nitrogen. Plants can use some of these in making new proteins, but others disappear in the air, and so nitrogen is lost from the cycle of life. But of all the common elements, nitrogen seems to be the one that does not come back into the life cycle by an automatic process.

The dead bodies of plants and animals on the ground and in the ground contain vast quantities of nitrogen compounds, as well as of fats and carbohydrates. These bodies are devoured by smaller organisms, down to the decay action of bacteria and fungi, and the material is finally returned to the soil and the earth. Particles of nitrogen at any moment present in a living thing, as well as the particles of other elements, are thus on their way out—in a constant process of circulating through the air and



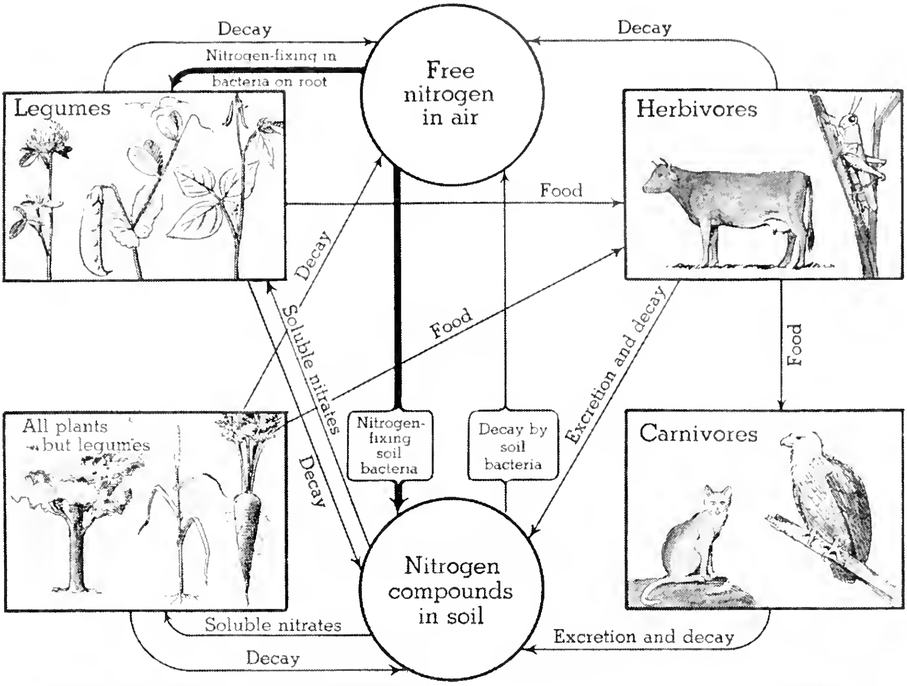
THE CARBON–OXYGEN CYCLE

The material of green plants consists in part of carbon derived from the carbon dioxide of the air. This carbon is passed on to animals as food, or returned to the air by respiration or by burning. Animals either pass on the carbon to other animals which eat them, or return it to the air by respiration. Some of the carbon is locked temporarily in the soil as excretions or as dead bodies. Through decay, the action of bacteria and fungi, this carbon is returned to the air as carbon dioxide

water, through the soil and other organisms. And while the atmosphere is nearly four-fifths uncombined, or "free", nitrogen, green plants cannot utilize it.

As a matter of public economy, people have found it worth while to save the manure of barnyards and even the sewage of cities for the nitrogen compounds that these contain. But in spite of all our saving, vast quantities of nitrogen are washed out to sea or thrown into the air beyond the reach of our common plants.

It has been possible to use nitrates, which are found as mineral deposits in certain places, especially in Germany and Chile. But the quantity of these nitrates is limited, and they are relatively expensive. On certain islands off the coast of South America there are extensive deposits of guano, or bird refuse, left there by countless birds that have built their nests upon these



THE NITROGEN CYCLE

Most plants take nitrogen from the soil, as soluble nitrates. Most animals receive nitrogen from plants or from other animals, as proteins in their food. Nitrogen in the bodies of plants and animals passes on to other living things as food or in the process of decay—which means the feeding of bacteria or fungi. Or it passes into the soil or the air as a result of death and decay. All living things eventually depend upon nitrogen-fixing bacteria, which return to the soil atmospheric nitrogen combined into forms that other living things can use

islands for hundreds of years. This guano contains nitrogen and other elements usable by plants in food-making, and it has been imported for use as a fertilizer. But the amount of guano is limited and constantly diminishing.

The nitrogen supply will probably last as long as the present inhabitants of the earth are likely to live. But society expects to outlive its individual members and must look ahead through its statesmen for those not yet born (see illustration above). Two solutions of the "nitrogen problem" have developed in comparatively recent years. One comes from a better understanding of living things; the other is an application of chemical knowledge.

Rotation of Crops If we grow several crops of grain on a farm, the yield tends to diminish in time because the nitrogen gives out. But we do not have to abandon the farm, nor need we import expensive nitrogen ferti-

Hugh Spencer

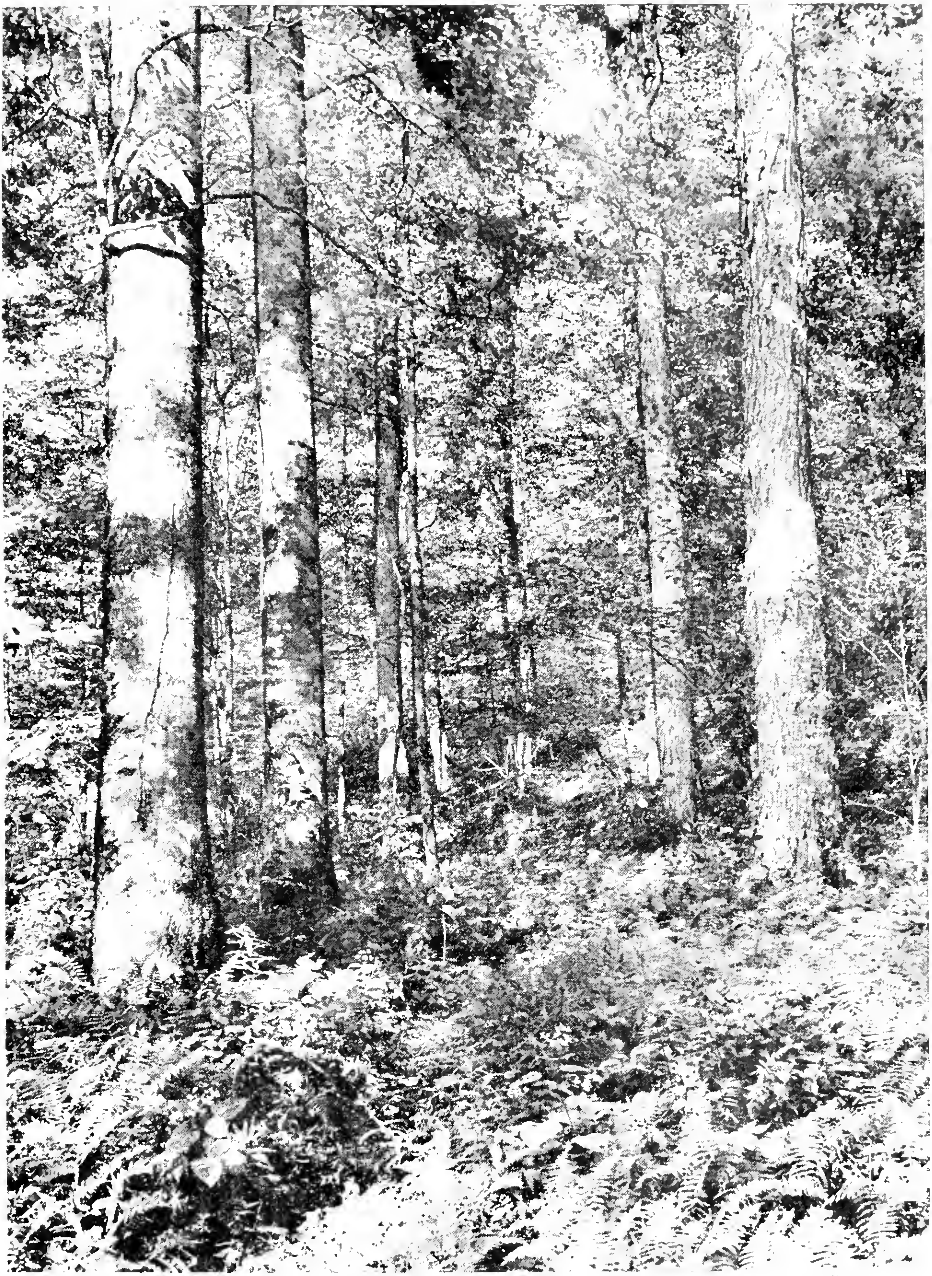
The swellings are inhabited by a vast number of tiny one-celled organisms that feed upon carbohydrates produced by the alfalfa plant. These guests absorb nitrogen from the air and combine it with material taken from the host, producing proteins. The alfalfa plant makes use of the excess protein. Nitrogen-fixing soil bacteria form similar tubercles on the roots of peas, beans, clover and other plants of this family. The bacteria produce much more protein than they can use, just as most green plants produce much more sugar or starch than they can use. As a result of this partnership the plants of the legume family contain much larger proportions of nitrogenous compounds than those of any other family. And a crop of such plants leaves more nitrogen in the soil than there was at the start

BACTERIAL SWELLINGS ON ROOTS OF ALFALFA

lizer. We have only to plant a crop of peas or alfalfa, and to make sure of the special kinds of bacteria that form the tubercles on the roots of these plants. It is now possible to buy cultures of the species of bacteria that are known to thrive best on any particular legume species.

In the course of the summer the bacteria in the tubercles will "fix" a large quantity of nitrogen from the air. Part of this they will make into proteins and consume in growth. Another part will be taken from them by the plants upon which they grow. And at the end of the season there will be present in the soil and above the soil (in the green plants) a great deal more nitrogen in combined form than there was at the beginning. The clover or alfalfa can be plowed under, and the nitrogen compounds in the plants thus added to the soil. After another season of this kind of crop enough nitrogen will be restored to the soil to support several crops of grain. This *rotation of crops* has been practiced by experienced farmers for many centuries, but it is only within the last fifty or sixty years that the significance of rotation has been understood.

Industrial Fixation of Nitrogen For the chemical solution of the nitrogen problem we are indebted to a Swedish scientist, Svante Arrhenius (1859–1927). Arrhenius worked out a process for making nitrogen combine with other elements under the action of electric currents. A process for combining nitrogen from the air with hydrogen, forming ammonia, was worked out by the German chemist Fritz Haber (1868–



United States Forest Service

VIRGIN FOREST

Under natural conditions where the soil is covered with forest or grass, the topsoil builds up slowly from the weathering of rock material and the accumulation of organic debris. Forest litter, organic matter in the soil, and roots absorb the rains and prevent water from washing away the soil

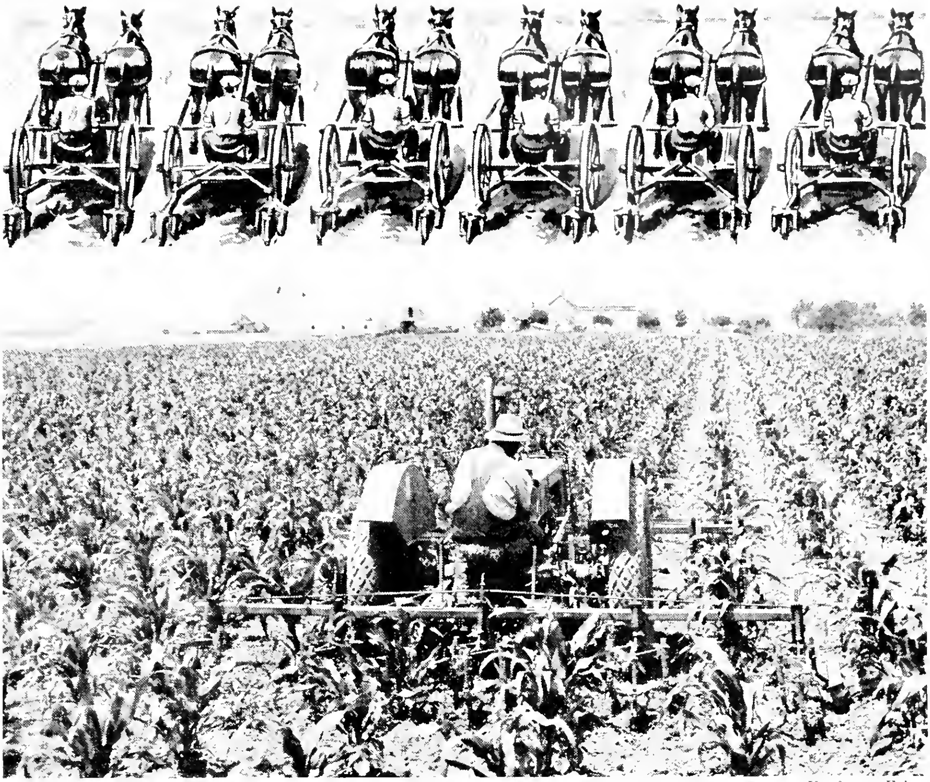
Soil Conservation Service (Ia-154)

DOWNHILL PLOWING INVITES EROSION

We have removed the native cover of trees, shrubs, vines and grass. We have pulverized the soil and exposed it to the elements year after year, as in row-crop or clean-culture farming. With this treatment, the rich soil is washed from the upper portions of slopes, burying the crops at the bottom

1936), and developed on an enormous scale in Germany. During the First World War the shortage of nitrogen compounds threatened to set a limit to further fighting, especially in the central nations. The nitrogen supply was important for military activities as well as for raising crops and for industry, since all explosives are based on nitrogen compounds. Haber's invention solved the nitrogen problem for the Germans, and enabled them to hold out for many months longer than would otherwise have been possible.

Haber died in Switzerland, an exile from his native land. In the meantime, the leading nations of the earth have been using his process, with various improvements, for converting atmospheric nitrogen into ammonia, nitric acid, and other essential compounds. These are widely used in fertilizers, in industry, and in explosives. In this way these na-



Kaufmann Fabry

POWER MACHINERY AND CULTIVATION

The use of power machinery has enabled us to plow and cultivate much more acreage than formerly. In this picture one man with a tractor cultivator is seen doing work as fast as six men can do it with horse-drawn cultivators

tions are becoming independent of natural supplies of nitrogen compounds, which most of them would otherwise have to import. But by the end of the first year of its participation in the Second World War, it had become necessary for the authorities in the United States to restrict the use of nitrogen fertilizers for all nonessential crops, lawns, and flower gardens.

Out of the Earth Those who live in the country usually understand how our lives depend upon the soil, but city dwellers come to think of the land as merely the surface, or place, upon which we live. We have seen that water is necessary for all life processes, and that the carbon dioxide of the air supplies material for the making of carbohydrates. All the other substances present in the bodies of plants and animals come out of the soil. Just as sunlight and sun-heat are the sources of our energies, so earth, water and air are the sources of our bodies. The crowding of a population may reduce food supplies through a shortage of soil materials.

A few generations ago thoughtful people looked forward to overcrowding in the fear that it would lead to great destruction of human life, or at least to great suffering. Indeed, the poverty and hunger of past times were largely due to man's inability to obtain from the soil adequate supplies of food. At the present time, however, our special knowledge and processes are so advanced that we are able to produce food and other essentials and many conveniences far in excess of the quantities needed for general comfort. We are, in fact, producing more foods of various kinds than we are able to distribute through existing systems of exchange—that is, through our business and financial machinery. This does not mean that everyone has all the food he needs. Even before the Second World War, not only was a very considerable part of our population misnourished, but a substantial part was actually undernourished.

Saving the Soil Increasing agricultural efficiency and activity does not assure abundance for everybody. Over large parts of the country we have made every cultivated acre yield three or four times as much food as had been usual in past generations. At the same time, we have removed from many areas tremendous quantities of minerals, so that the fertility of the soil is gone. And in addition, our ways of working the soil have ruined millions of acres by removing that portion of the earth's crust which is usable for crop production.

Under natural conditions, where the soil is covered with forest or grass, the topsoil builds up slowly from the weathering of rock material and the accumulation of organic debris (see illustration, p. 153). Even though some erosion takes place, the building-up processes more than make up for the loss. But we have removed the native cover of trees, shrubs, vines and grass. We have pulverized the soil and exposed it to the elements year after year, as in row-crop, or clean-culture, farming. As a result, soil has been removed from the top much faster than it is built up from below. Water and wind have carried the loose topsoil from the exposed hillsides and gullies into valleys and streams. After the topsoil has gone from the hills, the poor subsoil washes away, too, and in many cases covers the rich soil previously deposited in the valleys.

In Brief

Carbohydrates originate in green plants through the action of sunlight upon water and carbon dioxide in the presence of chlorophyl; oxygen is a by-product of this photosynthesis.

All other organic materials are derived from carbohydrates.

Both plant cells and animal cells synthesize fats from starches and sugars.

When supplied with carbohydrates and suitable mineral salts, non-green

plants, as well as those having chlorophyl, synthesize proteins, which contain nitrogen and other elements in addition to the carbon, hydrogen and oxygen derived from carbohydrates.

Single-celled green plants carry on all the activities that together make up being alive; all other cells of plants and animals depend upon chlorophyl-bearing cells for food.

Water and dissolved minerals absorbed by root hairs pass into the central cylinder by diffusion; from here they move bodily to other parts of the plant through special vessels; food is returned to the roots through other vessels.

The stem of a plant is an organ of support and of transportation. Water-conducting and food-conducting tubes of plant stems, as well as much of the supporting tissue, are arranged in bundles.

In monocot stems the fibrovascular bundles are scattered in the pith; in dicot stems they are arranged symmetrically.

The upward flow of water through the plant is due to osmosis in the roots and between cells, and to transpiration.

Animal life depends upon the activities of green plants; but the continued existence of green plants depends upon the oxidation of the organic substances which in nature goes on chiefly in the bodies of animals.

Various forms of living things are interrelated through the continuous interchange of materials described as the carbon cycle, the oxygen cycle, and the nitrogen cycle.

EXPLORATIONS AND PROJECTS

1 To demonstrate the iodine test for starch, add a few drops of iodine[1] to each of several test tubes prepared as follows: water only; water with cornstarch; water with piece of potato; water with white flour. Use small quantities of material and heat each tube to boiling. Note the blue-black color in the test tube containing starch. All kinds of starches produce a similar reaction with iodine; but chemists have found no other common substance that does so. We therefore take a blue-black color resulting from the addition of iodine to a substance to indicate the presence of starch.

2 To show the relation of light to starch-making in leaves, expose one of two healthy potted plants to sunlight and keep the other in the dark. At the end of the day, remove leaves from each plant and boil them about a minute to soften the tissues and to fix the starch. Then place in alcohol to remove the chlorophyl. When convenient, test the leaves for starch with an iodine solution. Compare results and formulate conclusions.

3 To show the relation of chlorophyl to starch-making, use a plant with variegated leaves, which have chlorophyl in some parts but not in others. After

[1]Tincture of iodine may be used, or a solution of 0.3 g of iodine crystals and 0.3 g of potassium iodide in 100 cc of water.

a day in sunshine, remove leaves and test for starch, as in No. 2 above. Describe results. What do they show?

4 To demonstrate the liberation of oxygen during photosynthesis, place two healthy potted plants under separate open-topped bell jars. Place a lighted candle in each bell jar and seal. After the candles are extinguished, allow the jars to cool for about 10 minutes; then carefully lift the stopper of each and insert a glowing splint. After making sure that there is no longer sufficient oxygen within the bell jars to keep a flame burning, place one jar in the dark and the other jar in the light. After several hours of sunshine, test the air in both jars for oxygen. Compare results and note conclusions.

5 To demonstrate the relation of light to stoma movements, place one of two similar potted plants in the dark and one in a sunny location. To the under surfaces of a few leaves on each, apply benzine with a small paintbrush. If the stomata are open, the benzine quickly penetrates to the inside, giving a transparent appearance. If the stomata are closed, it takes longer for the benzine to penetrate. Compare and note conclusions.

6 To observe the closing of stomata through the microscope, peel the lower epidermis from a leaf of a plant that has been exposed to direct sunlight for some time. Place in water on a microscope slide. Apply a drop of concentrated sugar solution to one edge of the cover-glass while watching a stoma through the microscope; draw the sugar over the epidermis, by applying a bit of filter paper to the opposite edge of the cover-glass. The sugar solution removes water from the guard cells by osmosis. How do the guard cells react? How would you explain what happens?

7 To show that *osmotic pressure* in the roots pushes liquid up, replace the shoot of a plant with a glass tube. Cut the stem off a healthy potted plant about an inch above the soil line; fasten a long glass tube to the stump by means of rubber tubing. Tie the rubber tubing securely on the stem with a string. Stick a similar glass tube in the soil. Keep the soil well watered. Compare results after one or two days and account for the differences.

QUESTIONS

1 What are the sources of all organic materials?

2 In the process of photosynthesis, what are the raw materials, what is the source of energy, what by-products are given off, and what "machinery" is essential?

3 What materials can both plant and animal cells synthesize from carbohydrates?

4 What elements are present in protein substances?

5 From the standpoint of food synthesis, what functions do the stems of plants serve?

6 How does girdling kill a tree?

7 How are various forms of living things interrelated through the carbon cycle? through the oxygen cycle? through the nitrogen cycle?

8 In what respect is the soil a natural resource?

We all feel that "life" is the central and the important thing in the world. We often speak of "life" as if it were a peculiar something or being which happens to dwell in certain natural objects, but which might as well exist elsewhere, or not at all. Yet what we know of "life" is what we can observe and understand about the activities of living plants and animals. These plants and animals, in turn, continue to be alive—to "have life"—only under rather special circumstances.

There are many kinds of substances in the world—some ninety elements and numberless compounds. Certain of these are present in all living things. A few are present occasionally, in a few species; and some are never found in living things, or may even be injurious. But in every case life goes on only on condition that these few elements are available—or rather certain of their compounds.

Living forms are found in all zones of the earth, in the waters and on the mountains, and in the deserts too. But everywhere water is an essential material condition of life. At the same time, water may be a source of injury. It is not merely that some of us might drown if completely submerged, but for various plants and animals an excess of water means a diluting of the intake, or a bloating of the tissues.

These materials contribute both to the *bodies* of living things and to the *processes* that characterize plants and animals. These constant chemical changes are in a sense both the processes of living and the conditions of living. These chemical processes continue under a wide range of physical circumstances. Each species, however, can live only within relatively restricted ranges. Thus living things exist close to the freezing point of water at one extreme and near the boiling point at the other. It is only the very simplest types of organisms that endure such extremes of temperature—different species at each extreme. But many of the back-boned animals are adapted to a wide temperature range by special protective coverings and by complex mechanisms that keep the inside of the body at a nearly uniform temperature.

Light influences protoplasm in various ways—even injuriously, when of extreme intensity. And yet it is upon sunlight that the whole world of plants and animals ultimately depends for its nourishment. For this form of energy makes possible the construction of carbohydrates out of water and carbon dioxide. And plants and animals utilize these compounds, first as sources of energy for their own activities, and second as bases for the proteins out of which new protoplasm is constantly being made.

The million or more different species, and the countless individuals in each species, all depend upon essentially the same basic conditions. All

organisms depend upon the same reservoir of water and soil and air. Yet the various life forms depend upon one another. Animals and plants lacking chlorophyl depend upon green plants for their food. But the continuous action of green plants depends in turn upon those other forms, which, by oxidizing their food, restore carbon dioxide to the air and the waters. These basic materials are in constant circulation, passing from the nonliving surroundings into plants and on into the bodies of animals. The vast total of "life" appears to be possible precisely because there are so many different kinds. Each species is completely surrounded by other "life" which contributes—and also takes away. There is a constant destruction, but there is also a constant restoring or balancing.

Millions of us satisfy our need for foods of various kinds, draw water (hot and cold) from convenient faucets, and buy our clothes according to means and taste without ever finding out that we are drawing upon the earth. The soil as the source of our material existence and well-being is actually managed by a diminishing fraction of the population. Fewer farmers and fishermen and hunters and foresters supply a larger population than lived here a generation ago. It takes fewer acres, as well as fewer men, to grow the crops and animals we consume. It is nevertheless of first importance that the entire soil be conserved, that the nation's entire water system be protected and developed, that all our forests and streams be maintained at a constant productive level. For, however far we may get from the land, our life is inseparably tied to the soil.

UNIT THREE

How Do Living Things Keep Alive?

1 How can living things without mouths get what they need?
2 How can the same food produce such different results in a calf and a baby?
3 What happens to food after it is swallowed?
4 How is it that our stomachs digest tripe but do not digest themselves?
5 What makes sawdust food for termites but not for horses?
6 What is it that makes one breathe faster at some times than at others?
7 What keeps the heart beating when other muscles get tired and quit?
8 Why are some animals warm-blooded and others cold-blooded?
9 How can animals tell what is injurious to them and what is useful?

The conditions for living are fundamentally the same for all species, and they are essentially the same for plants as for animals. We are impressed by the great variety of living forms that keep going, and under such wonderfully diverse conditions. The whale and the jellyfish live in the same ocean. The eagle and the lichen make their homes on the same bare rock.

How does any particular organism actually keep alive? How can two or more totally different species keep alive in the same surroundings? How can a similar animal manage in what appears to be quite a different setting? We know that every living cell depends upon a supply of food and oxygen. How, then, do the cells in the innermost parts of a person's body, or at the tips of the limbs, get the needed supplies?

Not only do these many different kinds of plants and animals keep alive, but many withstand the most extreme physical conditions. Their ways appear in each case to fit the special conditions, as well as the seasonal changes of their habitation. They are fitted to using a wide variety of foods. They are able also to adjust themselves to scarcity as well as to abundance.

Living protoplasm produces more and more of itself out of food that is quite unlike it. But out of the same kind of food an ox makes beef, a sheep mutton, a horse horseflesh, and a grasshopper something entirely different. We call it "assimilation" in every case, but what happens between the arrival of food in an animal and its becoming beef or mutton or human flesh?

As life goes on, wastes are produced. The simplest organisms move along, leaving their wastes behind them, just as primitive people move away when their camp sites become too littered and offensive. How do larger plants and animals dispose of the wastes their bodies produce? Do these

wastes threaten to obstruct life as they accumulate in the earth or in the water?

When we recover from some diseases, we become immune to them, but other diseases one may have again. Plants and animals recover from injuries. What changes take place in the body when it is sick? How does vaccination work? Why can we immunize against certain diseases, but not against others?

We may understand some of the similarities among plants and animals which we include under the broad idea of "life". But many questions are raised by the variety of living forms, and especially by the complexity of our own bodies and of other familiar species. How do such totally different things as a man and a clam, a bird and a mushroom, all manage to carry on essentially the same processes?

CHAPTER 9 · HOW DO LIVING THINGS GET AND MANAGE THEIR FOOD?

1. What happens to food after it is eaten?
2. How does the food which we place in the mouth and swallow get to the other organs of the body?
3. How is it that grass is suitable for the buffalo, flesh for the tiger, and wood for the termite?
4. Could meat-eating animals thrive if they were fed exclusively on vegetable matter? Or could cattle live on meat?
5. How do growing plants get at the food stored in seeds, roots, or underground stems?
6. How can some animals eat their meal and chew it later?
7. What connection is there between body build and feeding habits?
8. How are the activities of animals related to food-getting?
9. Why are some kinds of food more easily digested than others?

Some animals eat but a limited number of things. Others, like man, feed on a great variety. Species that feed on meat alone differ in structure and in behavior from those that feed on grass alone, for example. The talons and beak of a hawk, the rough, grasping tongue of the ox, the piercing mouth of a mosquito, and the biting mandibles of the grasshopper all seem to be especially related to getting particular kinds of food. In fact, the whole nature of an animal seems closely connected with his eating habits. Do the digestive systems of different animals vary, as the food-getting habits do?

How Do Plants Manage the Food They Make?

Digestion[1] The sugars which are first produced during photosynthesis are in many plants later changed into starches. Most of our common plants, however, produce starch in their leaves. Now starches are *colloids*—that is, they are like glue and cannot diffuse through cell walls—whereas sugars are *crystalloids*, or like crystals, and can diffuse through a membrane. Experiments show that in both animals and plants starches are changed into sugars.

When grains and other starch-bearing seeds germinate, the starch slowly changes into sugar. We can wash out of such sprouting seeds a substance called *diastase*. And we can show that in the presence of water, diastase converts starch into sugar. This process is called *digestion*.

[1]See Nos. 1, 2 and 3, pp. 182–183.

Diastase can be extracted from "malted" barley (that is, barley kept moist until the grains sprout), from rice, and from many other seeds. Malt is produced in quantities from sprouting seeds, and is used in making beer. A substance similar to diastase is found in human saliva and in the digestive juices of many other animals. The digestion of starch into sugar makes it possible for carbohydrates to pass through cell walls by osmosis.

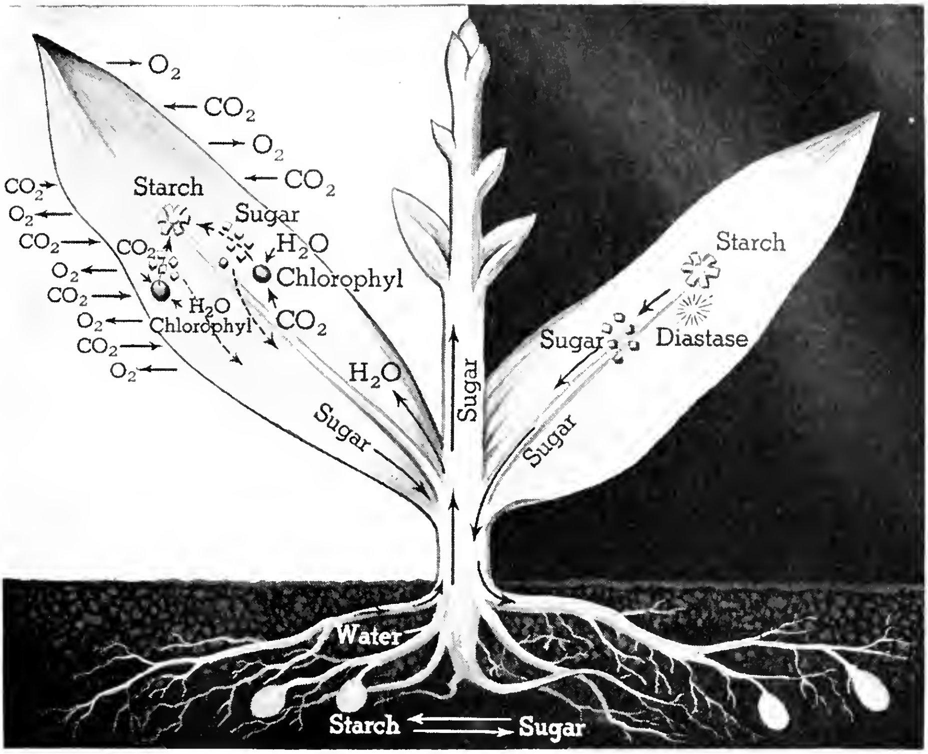
Enzymes Substances like diastase and the active part of the saliva are called ferments, or *enzymes.* Many different kinds are known. Like vitamins and hormones, enzymes *induce chemical changes in other substances* out of proportion to their amounts. These substances resemble what the chemists call a "catalyst"--something that seems to induce or accelerate chemical changes in other materials while remaining apparently unchanged itself.

Food Transportation Sugar formed in leaves during daylight diffuses out of the pulp cells and moves down through the bast or phloem tubes. When sugar is produced faster than it can be carried away, the excess is converted into insoluble starch. Starch thus accumulates in the leaf during the day. When darkness sets in, diastase converts starch into sugar, and this is then carried down into the stem or roots (see illustration opposite). That accounts for the fact that green leaves are full of starch in the late afternoon, but have no starch at all before dawn.

In the cells of potato tubers and of other organs that do not contain chlorophyl, starch is formed from sugar by the action of an enzyme. This process is just the reverse of digestion. The dissolved sugar in the leaves passes at first from cell to cell by osmosis, then in the sap by way of the bast tubes. In the root or tuber the sugar passes from the vessels to the pulp cells by osmosis, and is then converted into starch.

Digestion Universal The process of digestion seems to go on in nearly all living things. The ameba, which consists of a mass of naked protoplasm, swallows a solid particle into itself at any point and then digests the "food" inside the cell. Among the bacteria, which are the smallest living things known, each individual is a single cell consisting of protoplasm and cell wall. These tiny plants can get food only in a liquid state; yet many of them live on solid food that is not soluble in water. When meat or cheese rots, it becomes fluid. The rotting in such cases is the work of the digestive ferments secreted by the bacteria (see illustration, p. 166). When certain bacteria get established in the nose, for example, or in the throat or the appendix, the digestive action of their enzymes destroys living tissue, producing inflammation and soreness.

In higher animals like ourselves, a similar process of digestion takes place. But not every cell pours out digestive juices into its immediate neighborhood: only certain portions of the body produce and secrete such enzymes.



CARBOHYDRATES BY NIGHT AND BY DAY

In daylight, photosynthesis normally produces sugar faster than it can diffuse out of the cells and move into growing tissues or into underground parts. Surplus sugar in the leaves, and the sugar brought from the leaves into underground structures, become converted into starch. In the dark the starch that has accumulated in the leaves becomes transformed into sugar, which is carried into tubers or other underground "storage" structures

How Is Food Digested in Man?

The Human Food Tube[1] The mouth is the beginning of a long tube inside of which all the digestion takes place. This tube is called the alimentary canal, or food tube. It consists of several fairly distinct regions. It is ten or eleven yards long and is coiled or twisted in parts (see illustration, p. 167).

In the mouth, food is crushed and ground by the teeth. The taste of the food, the movement of the jaws, and the rubbing of the food against the inside of the mouth stimulate the *saliva* glands. As a result, a quantity of saliva flows into the mouth and becomes mixed with the food. An enzyme

[1]See No. 4, p. 183.

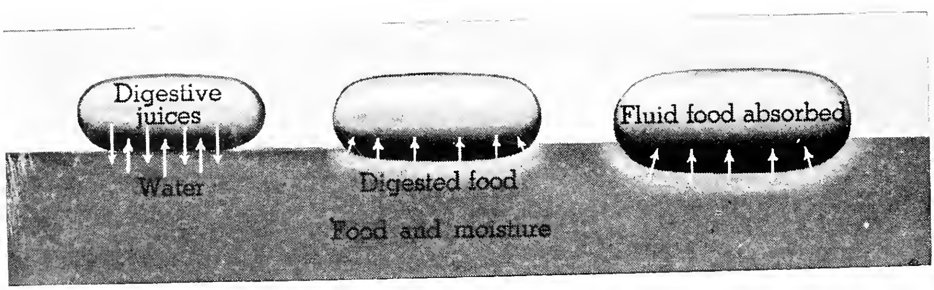
in the saliva changes the starch into sugar. Over 99 per cent of saliva is water, and this water dissolves salts and sugars.

The amount of enzyme is very small. The digesting of the starch depends upon (1) the ferment's reaching every particle of starch and (2) sufficient time for the ferment to act. Mixing saliva thoroughly with the food coats the mass with the slippery mucus of the saliva. That makes it easier for the mass to slide along into the throat and down the gullet.

After the mouthful of food has been thoroughly chewed, it is pushed back by the tongue and passed into the throat chamber, or *pharynx*. From the pharynx it passes directly into the gullet, or *esophagus* (see illustration opposite). Muscular rings in the wall of the gullet contract in series and so push the food toward the stomach. If you watch a giraffe or a horse drinking water from a pond or from a pail on the ground, you can see him swallow *up*—you can see one wave of contraction after another pass along the gullet, from the head to the trunk.

The Stomach[1] When nerve-endings in the mouth or nose are stimulated, glands in the stomach wall are aroused. These secrete stomach juice, or *gastric* juice. The fermentation started by the saliva continues until the mass of food gets into the stomach. Here the action is stopped by the acid stomach juice. The swallowed food is thoroughly mixed with the gastric juice by the churning action of the stomach muscles.

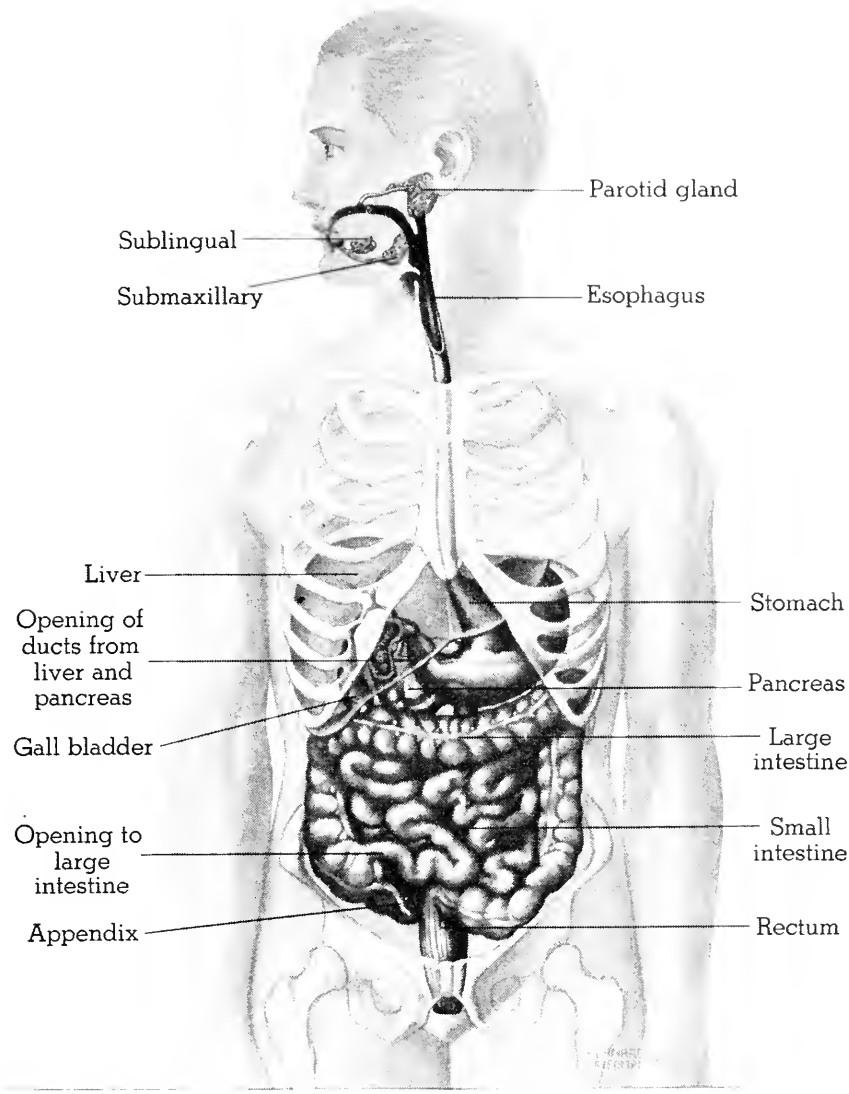
The gastric digestion breaks proteins into compounds that dissolve in water and diffuse through membranes. As digestion proceeds, the mixture in the stomach becomes more and more liquid and more and more acid. From time to time a quantity of the liquid passes into the *intestine*. Most



DIGESTION BY BACTERIA

In the presence of "food" and under suitable conditions of moisture and temperature, each cell discharges through the cell wall, by osmosis, one or more enzymes, or ferments. The enzymes digest the food material, changing proteins, for example, into simpler compounds that are soluble in water. The resulting fluid is then absorbed through the cell wall into the protoplasm, and is then assimilated

[1]See Nos. 5 and 6, p. 183.



THE DIGESTIVE SYSTEM IN MAN

of the contents of the stomach become in time changed to the consistency of a rather thick pea soup, and all pass on into the intestine.

The Bowles, or Intestines[1] Among the vertebrates the gut has two distinct divisions. The first is called the *small intestine*, and in adult human beings it is about one inch in diameter and about twenty-four or twenty-five feet long. It opens rather abruptly into the *large intestine*, which is about

[1]See No. 7, p. 183.

two inches in diameter and about five feet long (see illustration, p. 167). Pig gut and calf gut are used as sausage casing.

The wall of the intestine is thin and soft. The lining carries very small glands, and the outer layer contains muscle cells. The muscles run around the tube in rings, as in the esophagus, so that, as they contract, the diameter of the intestine is reduced. Waves of contraction start at the forward end (nearest the stomach) and pass backward along the whole length of the small intestine. The contractions move some of the contained mixture along, a short distance at a time. This movement is called *peristalsis* and is similar to the swallowing movement of the gullet. In vomiting, the peristaltic action of the food tube is reversed.

On leaving the stomach the food mixture contains in solution all the sugar that was there to begin with, all the sugar that was formed by the digestive action of the saliva; it contains the peptones resulting from the gastric digestion, and various mineral salts. This mixture contains whatever starch was not digested; any undigested proteins; and all the fats, which are affected by neither the saliva ferments nor by the gastric enzymes. In addition, there is a quantity of water, the acid remains of the juices, and the fibers and cell walls of the food material.

The fats and the remaining starches and proteins are digested in the intestine.

Intestinal Digestion[1] Near the beginning of the intestine two small ducts or tubes empty at a common opening. One of them leads from the largest gland in the body, the liver; the other from the pancreas (see illustration, p. 167).

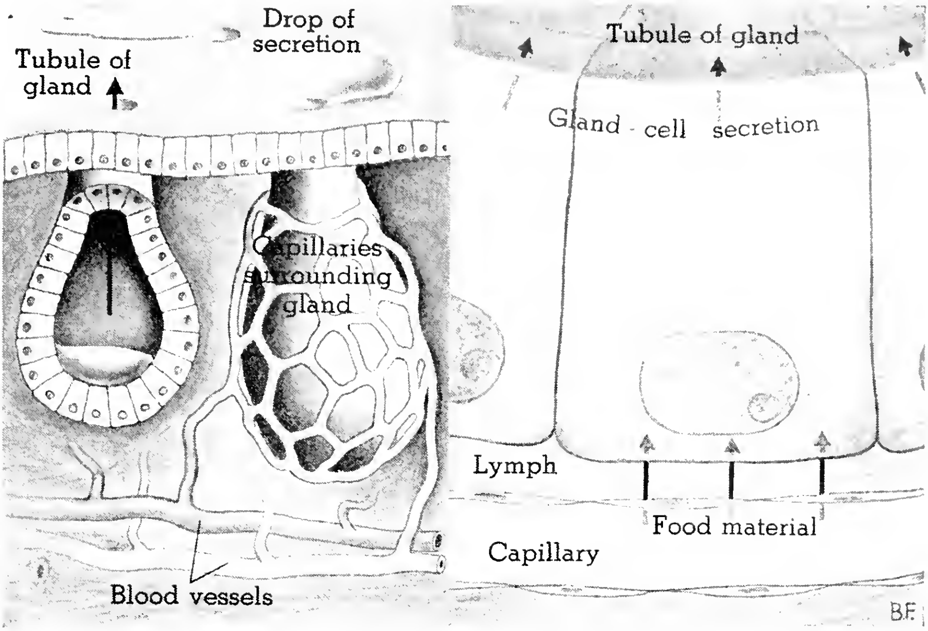
The juice secreted by the pancreas contains three important enzymes: (1) an enzyme that converts starch into sugar; (2) an enzyme that digests proteins into simpler compounds; (3) an enzyme that breaks up fats into *glycerin* and fatty acids.

The pancreatic juice thus contains ferments that digest all classes of organic nutrients. The fatty acids that result from the splitting combine with other substances into "soaps". Soaps and glycerin dissolve in water and are absorbed by cells lining the intestine. Farther along, where the intestinal fluid is acid, this kind of digestion is impossible.

The liver produces *bile*, or gall, which contains no digestive enzymes. But the bile neutralizes the acid of the gastric juice and so furthers the work of the pancreatic enzymes, which are active only in an alkaline solution. The bile also influences the diffusion of soaps and fatty acids into the cells of the intestine.

The bile consists largely of materials that are of no further use in the body; the liver is thus also an excretory organ.

[1]See No. 8, p. 184.



HOW A GLAND SECRETES

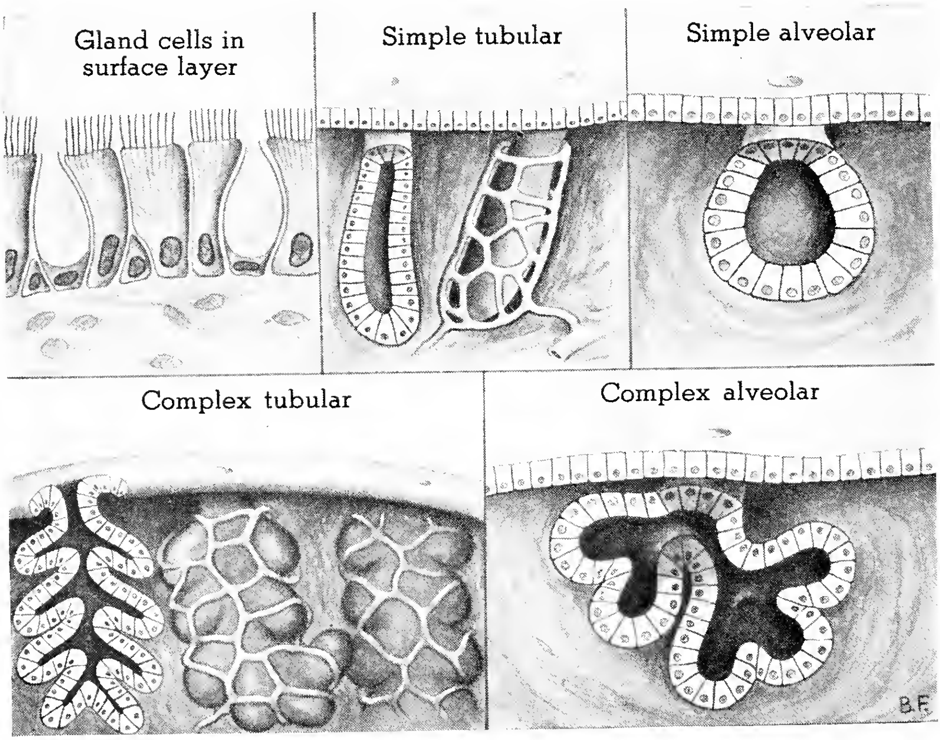
Materials are transformed in a gland by chemical action in the epithelial, or lining, cells. The raw materials are derived from the blood stream or the lymph. The specific substance formed by the gland is diffused out of the epithelial cells into the tube or pit which they surround. The secreted substance is discharged from the gland through a duct, or little tube. The excretions of the specific secreting cells are removed by osmosis into the lymph or blood, as in the case of other body cells

Glands and Juices We have seen that the carbohydrates, fats and proteins are split into simpler compounds by specific ferments in the juices secreted by glandular organs. But there are many sugars and many fats and many proteins. Among the enzymes secreted by glands in the walls of the small intestine, some convert sucrose and other complex sugars into simpler ones. A certain enzyme will split one sugar, but will have no effect whatever on another sugar. Proteins, when digested, break first into proteoses, then into peptones, then into numerous peptids, until finally only many kinds of amino-acids are left. At each stage in the cleavage of a protein into the fifteen or more amino-acids, a special enzyme operates.

There are many kinds of glands besides those which produce digestive juices. For example, the tears come from special glands, as do sweat, milk, the mucus. The shell of an oyster may be considered as a precipitated lime secreted by skin cells acting very much like glands. The kidneys are really large glands which remove wastes from the blood, making them into urine, and then discharge the urine through special ducts (see page 218). Still

other "glands", as we shall see later (Chap. 16), are characterized by having no ducts.

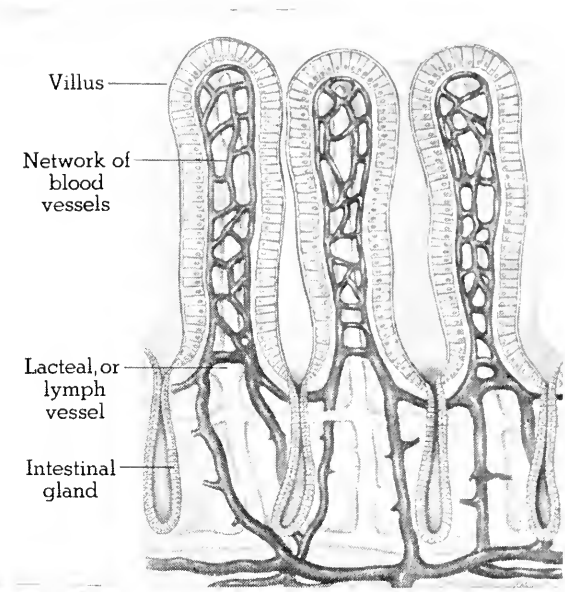
Absorption of Digested Food Tiny projections into the cavity of the small intestine increase the absorbing surface of the lining several hundred times (see illustration opposite). These projections are called *villi* (singular, *villus*), from a Latin word meaning "shaggy hair" which gives us also *velvet.* The villi act both as absorbing and as transforming organs. That is, the materials they absorb become chemically changed before being passed on into the *lymph*, the colorless fluid which surrounds all the living cells in the body. They thus behave like glands, only, so to say, in reverse. For glands normally absorb materials *from* the lymph, transform them chemically, and then pass out new substances.



TYPES OF GLANDS

Glands consist essentially of secreting cells arranged in a layer, which tends to fold into depressions, or pockets. A gland may thus consist of one or a few cells secreting on the surface, or it may consist of a simple tube, more or less enlarged toward the bottom into an "alveolus", or pit. In some glands the tubes branch and subdivide extensively, so that a great deal of secreting surface supplies one opening or tube. The liver, the largest gland in the body, is a compound tubular gland. Alveolar glands may also branch and become complex—the pancreas, for example

The velvety appearance of the inner surface of the small intestine is due to the multitudes of projecting villi. The layer of cells covering these villi absorbs digested food from the food tube. The digested food, after some chemical changes, diffuses out into special lymph tubes, the lacteals, and finally gets into the blood. The action of the villi may be compared to that of glands; but whereas the movement of materials is from the blood stream to the special secretions in the case of the glands, it is from the food supply to special blood substances in the case of the villi



THE LINING OF THE INTESTINE

The mixture in the intestine now consists of (1) many crystalloids in solution, (2) many colloids in the process of being converted into crystalloids, and (3) solid substances that are not changed under conditions that exist in the gut.

When the dinner that you have eaten reaches the end of the small intestine, most of its carbohydrates, proteins and fats have been absorbed by the villi and passed into the lymph and blood. There are left in the intestines chiefly (1) the undigested (mostly indigestible) fibrous and cell-wall parts of the plant or animal tissues eaten, and (2) the chemically changed material from the various glands that have poured their products into the food tube along the way. This mass of refuse now passes into the large intestine (see illustration, p. 167).

The Large Intestine In the large intestine the enzymes of the digestive juices may continue to act for some time. The lining of the intestine continues to absorb fluids, although there are no villi in the large intestine. Finally, the only chemical changes going on are those produced by the millions of bacteria that are present.

The mass of material that accumulates toward the end of the large intestine is of no further use to the body. To this refuse are added dead cells from the lining of the intestine and waste materials absorbed from the surrounding fluids and cells. The refuse, or feces, is normally removed from time to time. Birds, having no large intestines, throw off the refuse about

Products of Glands with Ducts

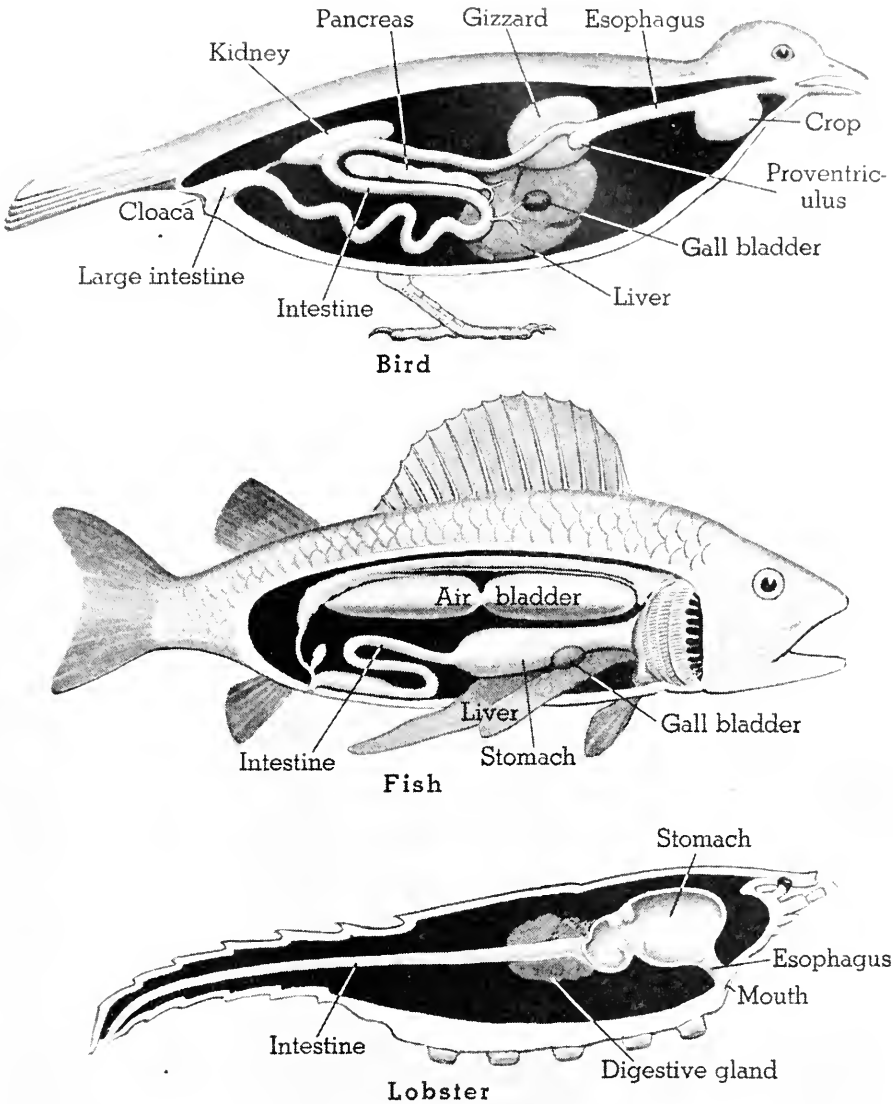
FUNCTIONS	GLANDS	PRODUCTS
Digestive	Salivary	Saliva
	Gastric	Gastric juice
	Pancreas	Pancreatic juice
	Liver	Bile
	Intestinal	Intestinal juice
Lubricant	Mucous	Mucus
	Serous	Serous fluids
	Lachrymal	Tears
	Sebaceous	Oil
	Wax glands in ear canal	Wax of the ear
Cooling	Sweat glands	Perspiration
	Mucous glands of respiratory tract	Mucus
Food	Mammary	Milk
	Villi	Fats and proteins from absorbed foods
Excretory	Kidneys	Urine
	Sweat glands	Perspiration
	Liver	Bile

as fast as it passes from the small intestine to the rectum. Other animals and human infants automatically throw off the refuse from time to time.

What Do Other Kinds of Animals Do with Food?

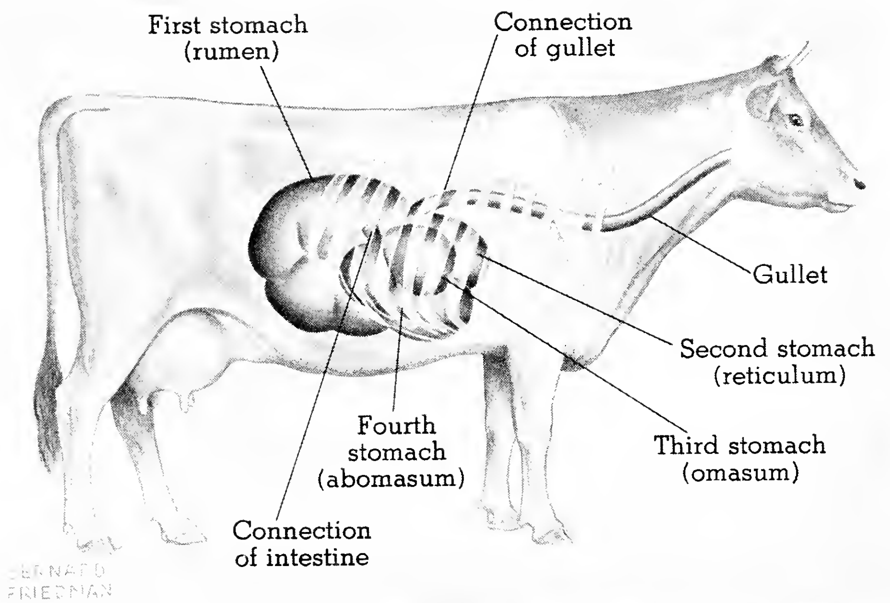
Kinds of Feeders The digestive system in the human body disposes of the proteins, carbohydrates, and fats from a great variety of sources—plants and animals of many different kinds. Animals are of course restricted in their diet by what happens to be present in their immediate surroundings. But many species are limited also by their natural equipment for making the food available. The cow eating grass, for example, disregards the flies which are gobbled up by the frog not far away. The crow eats worms and grubs and the seeds of many plants. The squirrel in the same region concentrates on nuts. Some animals kill others and devour them without special preparation. Snakes and owls swallow their prey whole, digest what is usable out of the mass, and eventually reject the bones, hide and hair. Related to the many ways of getting food, to the kind of food obtained, and to the conditions of food-getting, are the distinctive digestive systems of various species of animals.

Chewing at Leisure Several of the even-toed ungulates, or hoofed animals, such as cows, sheep, goats, antelopes, deer, giraffes and camels, browse until they have filled their first stomach, the *rumen*, with unchewed roughage composed of grass and other vegetation. They then lie down in



DIGESTIVE SYSTEMS OF BIRD, FISH AND LOBSTER

In all chordates and arthropods (elongated, bilaterally symmetrical animals) the food tube extends the length of the body from the mouth to the anus, and has various glands opening into it. In birds the gullet has a curious pouch, the crop, in which food may be retained indefinitely and later either swallowed into the stomach or regurgitated through the mouth. The glandular portion of the stomach, the proventriculus, is distinct from the grinding portion, or gizzard. In the lobster the stomach is in the head



THE STOMACHS OF A CUD–CHEWING ANIMAL

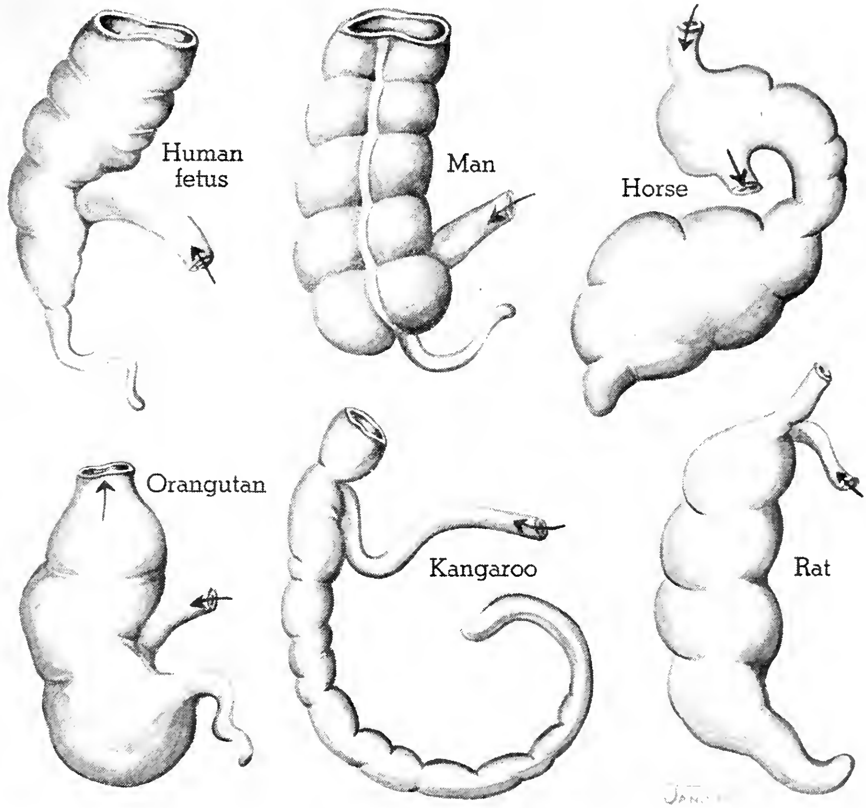
The cow swallows food into the first stomach without chewing it. The contents of the stomach are returned to the mouth in small quantities when the animal is lying quietly, and thoroughly chewed. The mixture of saliva and ground food is then swallowed into the second and third pouches of the stomach, where salivary digestion continues. In the fourth stomach gastric digestion of protein goes on

some comfortable spot, *regurgitate* a wad at a time and grind it to bits. When the cud is thoroughly macerated, it is swallowed into the second stomach, and on it goes through the remainder of the food tube. Bacteria in the food tube decompose the cellulose of the plant tissues, exposing the cell contents of the swallowed material to the digestive juices.

Off the Main Line In many animals, the horse, rabbit and rat, for example, food in the digestive tube is held up for a considerable time in a blind gut. This side branch of the large intestine is located at the junction of the small and large intestines, and is called the *caecum*, from a Latin word meaning "blind". Chickens and doves have two caeca. Bacteria in the caecum digest the cellulose of plant tissues, as they do in the first stomach of ruminating animals. At the end of the caecum, in most mammals, is an extension or appendix. In some species this is "wormlike" and hence is called the "vermiform" appendix (see illustration opposite). In many the blind gut is small and has a poor blood supply. An infection of the appendix, a condition known as "appendicitis", is often serious.

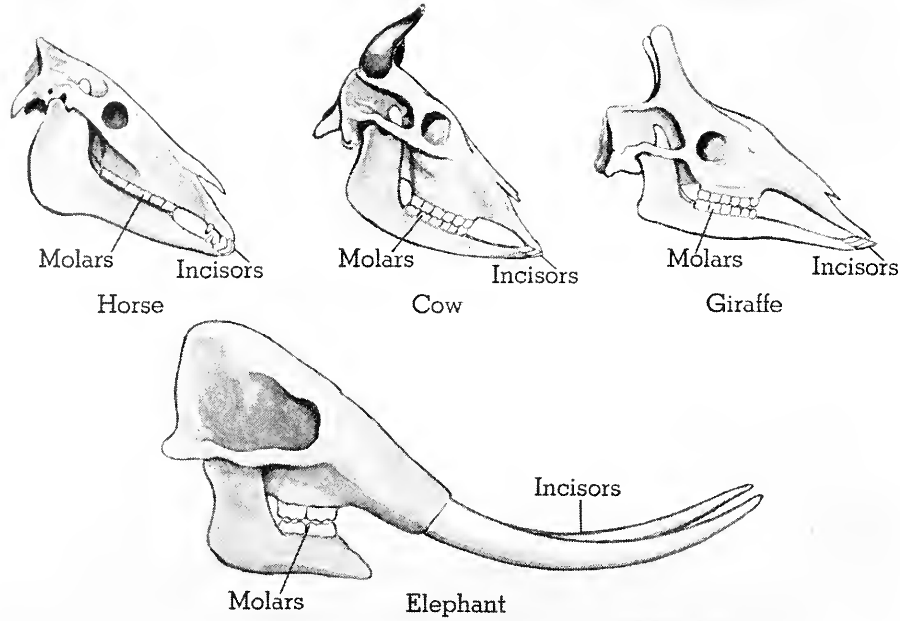
Food-Getting and Food-Using Digesting food is but a special detail of the total activity of a living organism, and it is related to the whole manner of living. The main divisions of the food tube are much alike in all classes of vertebrates, and even in other classes; but many differences in detail are seen to be related to the kinds of food eaten, to modes of locomotion, to the sense organs, to the whole scheme of habits. Thus, most predatory, or preying, animals have a short food tube; this appears to be related to the relatively high protein content of the food.

All predatory animals, whether tiger beetle or shark, falcon or rattler, squid or lion, have powerful offensive weapons. Tigers, lynxes, leopards, and other cats have supple bodies, sharp claws, pointed teeth, and a stealthy



THE VERMIFORM APPENDIX

The blind sac is relatively smaller in some orders of mammals than in others. It is least active in digestion among the primates. In the human species, it is actually larger in the fetus than in the adult



THE TEETH OF HERBIVOROUS ANIMALS

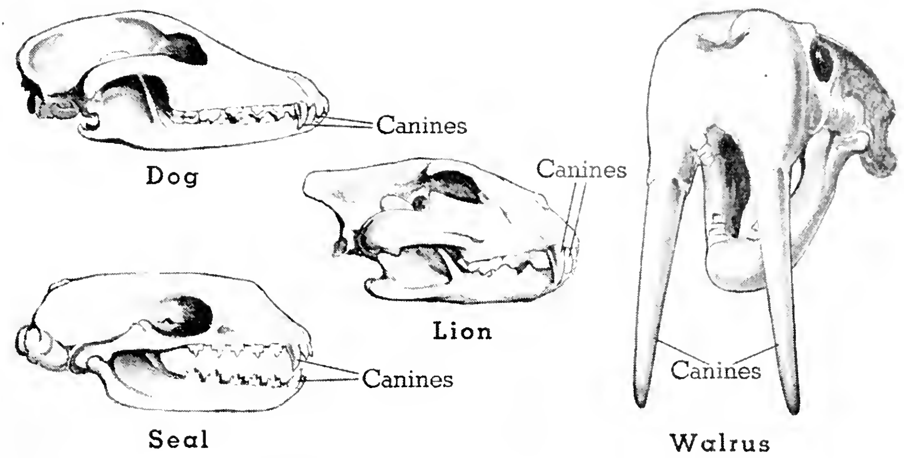
The sharp incisors cut or tear the leafy material. The broad grinding surfaces of the molars macerate or shred the food

yet ferocious behavior effective in capturing and killing prey. The weapons of wolves and other members of the dog family are similar, but their hunting habits are different.

Among the birds there is a great range in size, from the humming-bird, which weighs less than an ounce, to the ostrich, which may attain a weight of over 200 pounds. There is a corresponding range in foods, from the nectar of flowers and insects caught on the wing to nuts and fruits, frogs, rabbits, sheep, and even larger animals (when dead), as in the case of the buzzards. And there are corresponding types of beaks and also of feet.

The great French anatomist Georges Cuvier (1769–1832) found the various organs of the birds which he studied so closely related to the ways of life that he was able to tell a great deal about the habits of an unknown species from examining merely one of the bones (see illustration, p. 178).

Birds, like ruminants, cannot stop to chew, but gulp their food. Many also store the swallowed mass temporarily, in a pouched enlargement of the food tube called the crop (see illustration, p. 173). Birds swallow small stones into a muscular grinding organ called the *gizzard*. Food passes quickly through the relatively short digestive tract of birds.



TEETH OF FLESH–EATERS

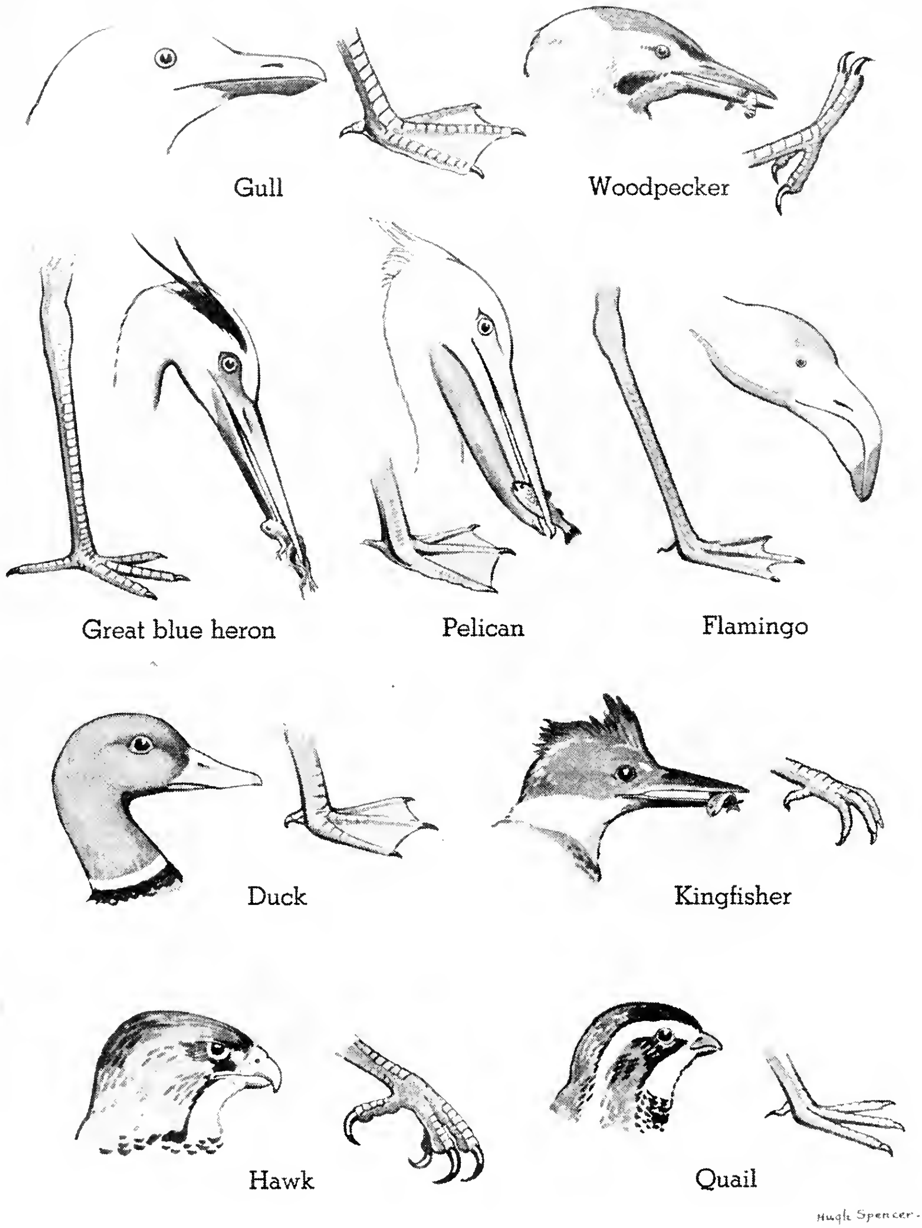
The large canine, or "dog", teeth act as weapons in fighting or grasping. The short incisors cut tough tissues, and the heavy molars break and crush bones

Takers and Sharers Nearly every species of plant and animal acts as an unwilling "host" to one or more life forms that live at its expense. Common examples of *parasites*, as such uninvited guests are called, are the leech, the sheep tick, the liver-fluke and the bedbug. Many diseases result from the destructive action of parasites, such as the malaria plasmodium, the *Treponema pallidum*, or syphilis parasite, the hookworm, and the bacteria of many common diseases.

An interesting partnership between two species is seen in the *symbiosis* or "living together", of a species of termite and certain protozoa that live within its digestive tract (see illustration, p. 179). The termite lives in dead wood, in the forest or in buildings, mining through it by chewing the wood into small bits, which it swallows. Within the digestive tract live the protozoa which produce enzymes that change the cellulose into soluble sugars.

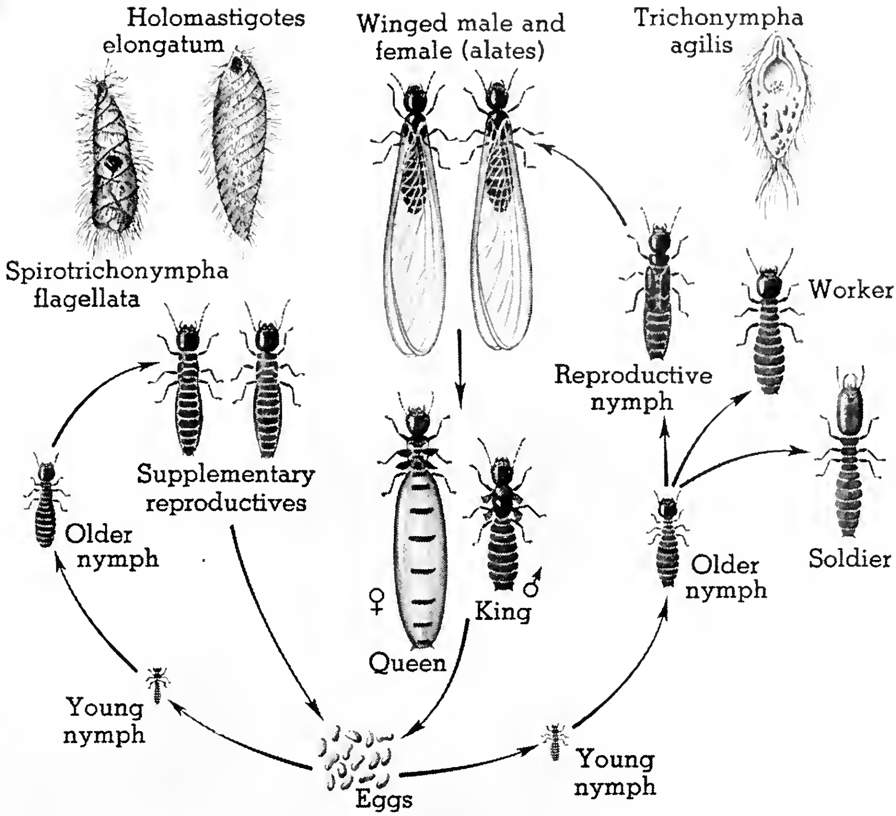
Periodic Feast and Famine All animals convert some of their surplus food into fat. This is stored within the body and is used in times of emergency or of food shortage. Some species, the bear and the woodchuck, for example, feed and fatten during the summer months and spend the cold months in a deep sleep, called *hibernation*, or "wintering". At this time they live on the food stored during the summer feasting.

Another illustration of getting food while the getting is good is seen in the distinct stages characteristic of many species of insects (see illustration,



FOOD–GETTING ORGANS

A beak is a beak, but the bill of a hawk is different from that of a heron. The distinctive beaks of various species of birds, like their feet and legs, are related to distinct modes of life—which include, of course, the character of food available and especially the ways of getting food



SYMBIOSIS AMONG ANIMALS

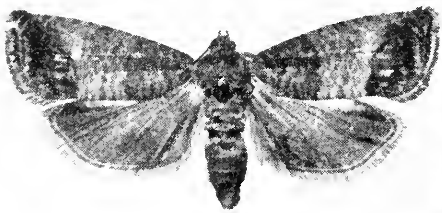
The flagellates which live within the digestive tract of the termites change wood into soluble carbohydrates. The termite furnishes the protozoans a comfortable shelter and keeps them supplied with small bits of wood—which the termite can break down mechanically, but cannot digest

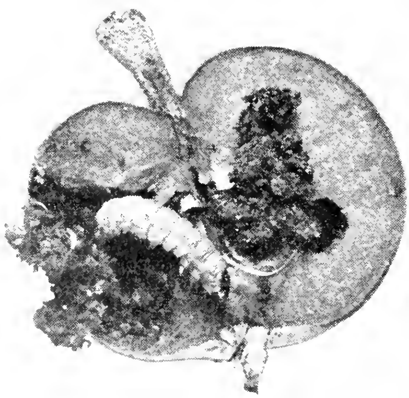
p. 180). Very many of such species take practically all the food for a lifetime during the larval stage, living the rest of the time on accumulated reserves.

A third type of intermittent feeding is illustrated by the golden plover. This bird summers in the arctic and then migrates to southern South America. It travels 2400 miles in a nonstop flight, on energy from the fat stored within its body.

The intermittent feeding of animals is not unlike the habits of many plants. In the common annual plants that start from seeds and end in seeds within a few months, there is a long stretch of time during which metabolism is at a standstill. The food for the renewal of life in the spring is the

reserve packed in the seeds. Such biennial plants as carrots, beets, parsnips, turnips, and many of the dock-weeds store food in large fleshy roots during the first growing season. Then, in the following spring, the food stored in the roots is used in developing a new shoot, which bears seeds before the end of the second summer. Many perennial plants—in fact, all that pass through a dormant stage during the winter—store food in the roots or stems during the growing season. And from this store they develop new buds and leaves the following spring. Asparagus, as marketed, consists of tender young shoots grown from food stored in roots and underground stems during the preceding seasons.

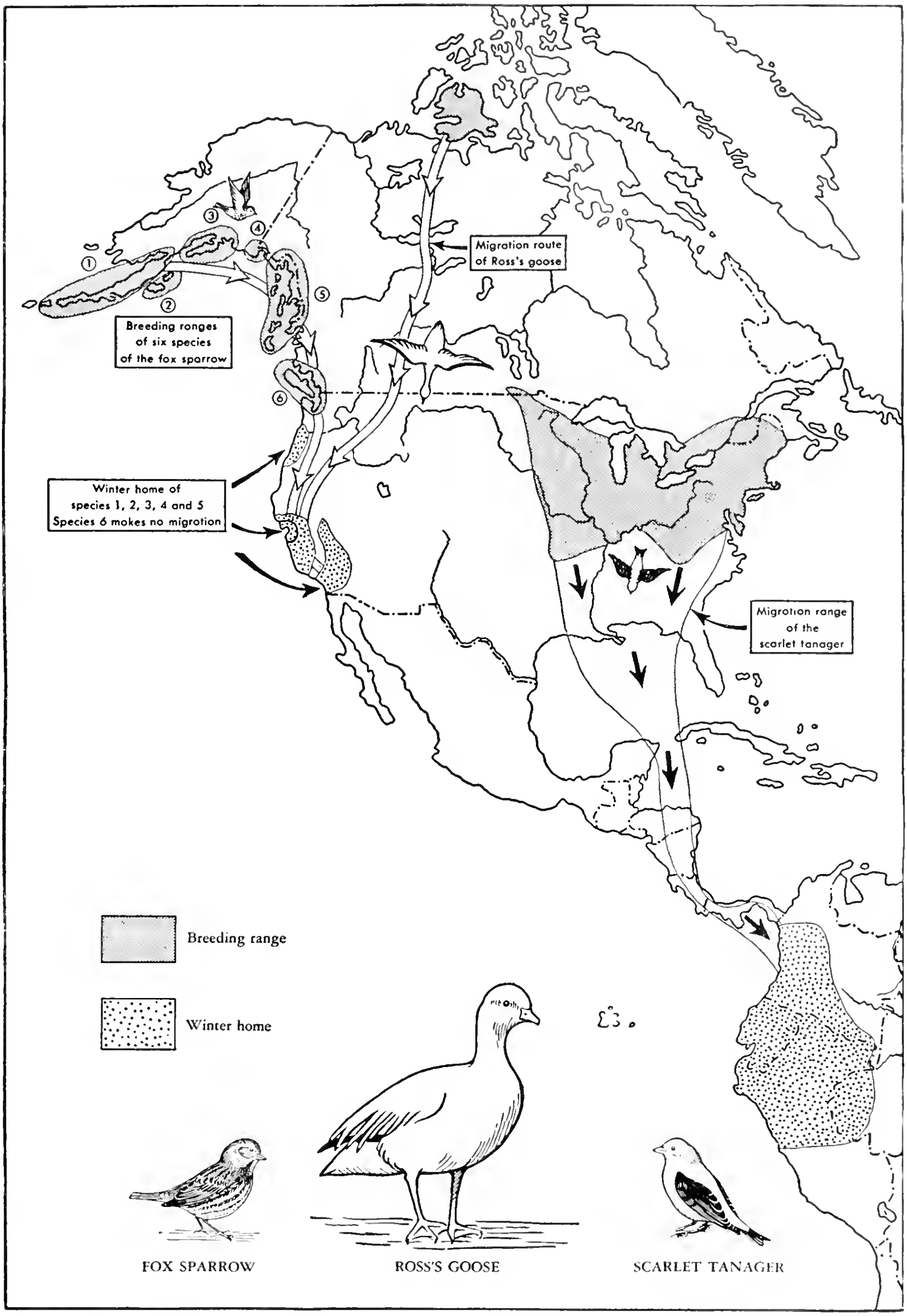




United States Bureau of Entomology and Plant Quarantine

LIFE HISTORY OF THE CODLING MOTH

The "worm" of the apple is the larva of the codling moth, which feeds only during the larval stage. In early summer the larva enters the open end of newly set green apples, where the tips of the sepals come together. It feeds on the apple pulp and grows larger. Early in July it emerges from the fruit and pupates on the bark. The adult comes out of the pupa and later lays eggs on the bark of twigs. These eggs hatch into larvae, which eat their way into the sides of apples. The full-grown larvae come out of the apple in late fall and form pupae in protected places under the bark, where they pass the winter. The moth thus produces two broods in one year



BIRD MIGRATION

The winter home, the breeding range, and the migration routes of three North American birds

In Brief

In plants and in animals, starches, proteins, and other nutrients are converted into soluble crystalloids by the action of various enzymes.

Excess sugar produced in leaves is converted into starch by the action of an enzyme—a process just the reverse of digestion. At night starch is converted into sugar by the digestive enzyme diastase, and the sugar is transported to other parts of the plant through the phloem tubes.

Digestion takes places in plant cells which make or store food. Single-celled animals digest food within their bodies. Bacteria give out enzymes which digest food in the surrounding medium. Higher animals carry on digestion in specialized organs.

Food entering the mouth passes successively through the pharynx, gullet, stomach, small intestine and large intestine. Food is moved along through the alimentary canal by peristalsis. Undigested portions are discharged from the body through the rectum.

Digestive juices are produced in special glands and delivered by ducts into the food canal. Other products of glands with ducts are lubricants, cooling secretions, excretory substances, and food.

Starch is changed to sugar by digestive enzymes present in the saliva and in the pancreatic juice. Complex sugars are changed to simple sugars by several specific enzymes present in the intestinal juice.

Proteins are split into amino-acids by enzymes in the gastric, pancreatic and intestinal juices.

Fats are split into fatty acids and glycerin by an enzyme secreted in the pancreatic juice. This digestion requires an alkaline medium, which is furnished by the bile.

Digested food is absorbed and transformed by the villi, specialized absorbing organs that project into the cavity of the small intestine.

Plants and animals accumulate surplus food in their tissues, and then use it when new supplies are scarce.

EXPLORATIONS AND PROJECTS

1 To determine which food substances diffuse through osmotic membranes, place dilute starch paste, corn sirup, olive oil, and raw egg white in four wide-mouthed bottles, tie bladder membranes tightly over the tops, and suspend in jars

of water overnight. Test the material in both the bottles and the jars for the appropriate substances.[1]

2 To find out whether digestion takes place during germination, test the cotyledons and endosperms (*a*) of several dry seeds for starch and simple sugar and (*b*) of similar seeds after they have sprouted. Compare and explain your findings.

3 To extract the starch-splitting enzyme *diastase* from germinating seeds and grains, grind a mass of seedlings in which the sprouts are about half an inch long in a mortar; just cover with water and let mass stand a half hour. Filter off clear liquid and test for diastase by trying to digest starch with it.

4 To show the digestion of starch by saliva and by diastase, mix dilute starch paste with saliva and with diastase, set it in a warm room overnight, and then test for simple sugar and for starch. Do tests on saliva, diastase and starch paste, as well as on the mixtures which have stood overnight. Account for your results.

5 To demonstrate the effect of rennin on milk, add a little rennin, dissolved in water, to a cup of fresh, lukewarm milk, and let stand for ten minutes.[2] (Rennin acts on milk in the stomachs of animals as it does on the milk in the vessel.) What relation has this action to digestion?

6 To find out how proteins are digested in the human body, expose small cubes of boiled egg white to the different digestive fluids and note the effects.[3] Gather some saliva in a test tube. Place protein cubes in four test tubes containing respectively (*a*) water, (*b*) saliva, (*c*) gastric juice, and (*d*) pancreatic juice. Leave all together in a warm part of the room or in a laboratory incubator. The next day examine the cubes of protein to determine whether and how much they have been "eaten away". Tabulate results observed and note conclusions.

7 To study the digestive organs and their movements:

To observe peristalsis, kill a suitable animal quickly, and open the abdomen to expose the large intestine.[4]

[1]For starch, test with iodine (see page 157).

For simple sugars, as grape sugar or glucose, use Fehling solutions. Add about 5 cc of Fehling copper solution to the solution to be tested, and boil for a few minutes. Then add a similar amount of Fehling alkaline solution. If a slight amount of sugar is present, the color will be green; if more is present, yellow; if still more, orange; and if there is a considerable amount, red.

For the liquid fats, observe the fluid in the bottle and in the jar to see if any oily drops are present. (To test for fats in solid substances, crush them, pour on ether to dissolve any fat present, then pour ether on a piece of paper. A permanent translucent spot indicates presence of fat.)

For proteins, add a few cubic centimeters of nitric acid, and heat. Nitric acid turns proteins to a yellow color. If sufficient sodium hydroxide is then added to make the solution alkaline, the protein turns an orange color.

[2]Rennin is available in various trade preparations.

[3]To make artificial gastric juice, dissolve dry pepsin in water and add a few drops of hydrochloric acid. To make artificial pancreatic juice, add pancreatin to water, with a small pinch of sodium bicarbonate.

[4]Frogs, chickens, rats and guinea-pigs are all suitable for use in this study. It is interesting to use all of them, for the internal structures vary significantly. To observe peristalsis, open the animal immediately after it is anesthetized. The frog may be "pithed" by quickly destroying the brain with a needle or a sharp knife.

To view the digestive structures, open on the ventral side to expose the digestive organs in their normal position within the body. Note the relative arrangement of the liver, stomach and intestines. Also, note the fine connective tissue carrying blood vessels, which connects with the folds of the small intestine and holds them in position. Beginning at the anus, cut out the intestinal tract of each of the animals and sever connective tissues so that the intestines may be stretched out full length; compare the organs in the several animals.

8 To show the effect of pancreatic enzyme on fat, place a few drops of feebly alkaline emulsion of olive oil containing blue litmus upon a microscope slide, and add a little pancreatic juice. Under the microscope note that the tissue becomes surrounded by a red halo. This shows a formation of *acid*; it is due to the fatty acids set free from the fat by the enzymes present.

QUESTIONS

1 Why cannot the cells of our body make use of the food as we receive it from the kitchen?

2 What kind of nutrient is digested by the mouth juices?

3 Why is it necessary to chew food that is not digested by the mouth juices?

4 How can plants, which have no stomachs, digest food?

5 How can we show that saliva acts upon starch but not upon protein?

6 In what respects are enzymes like vitamins? In what respects are they different?

7 How do digested nutrients reach the body cells?

8 How are undigested portions of food moved along through the food tube?

9 What glands secrete digestive juices, and what effects are produced by each juice?

10 What functions other than digestion do gland products carry on in the body?

11 In what ways are the digestive systems of various animals especially adapted to digesting distinctive kinds of foods?

12 What makes plant tissues, as a rule, harder to digest than animal tissues?

13 How is it possible for a person to live after a surgeon has removed his stomach?

14 How are various species able to survive on an intermittent food supply?

CHAPTER 10 · HOW DOES FOOD REACH THE DIFFERENT PARTS OF THE BODY?

1. Is the sap of plants the same as the blood of animals?
2. Do all animals have blood?
3. How does the blood help to keep us alive?
4. Of what is blood composed?
5. How does exercise speed up the heart?
6. Do all animals have organs corresponding to hearts?
7. How does blood clot?
8. How does the blood keep the body warm?
9. What can the doctor tell from feeling the pulse? or from listening to the heart?
10. How can the blood of one person be made to work in the body of another?
11. Can the blood of one animal be transfused into the body of another?
12. Why must blood be "typed" before a transfusion is made?

In all except the very smallest plants and animals there is some way of distributing materials among the different parts of the body. In the common plants one set of tubes carries water and dissolved salts from the roots, by way of the stems, to the leaves; and another set of vessels carries organic food from the leaves to other parts of the plant. The two currents are independent of each other. They consist of different materials and are not connected at any point.

The red fluid that spurts out when the flesh is cut has always impressed mankind as both important and mysterious. People have explained almost everything they could observe or imagine about life by pointing to the blood. It is truly a marvelous juice! The very color has itself been exciting and has been widely used as a symbol. On flags and emblems it has represented the blood that men have shed to ensure their rights and freedoms. It has also represented the blood brotherhood of all humanity.

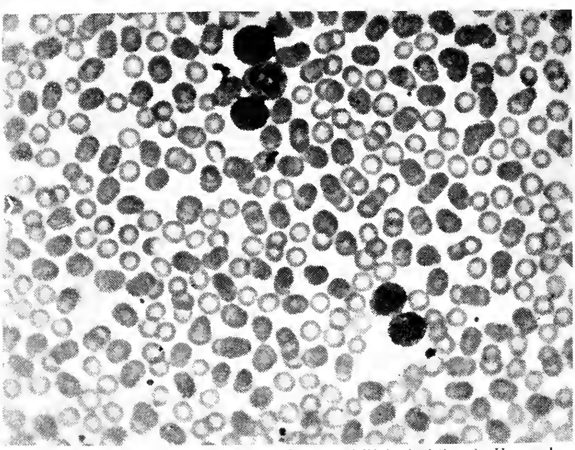
Some of the ancient Greeks held the notion that the blood moves. That the heart actually pumps blood and keeps it in circulation was first worked out by the English physician William Harvey (1578–1657). Harvey's argument, from the facts then known, was perfect. There was in it, however, one missing link: *how does the blood get from the arteries to the veins?* Harvey could not tell. He was certain only that somehow it *must.* Nobody then could know either the structure of the blood or the existence of capillaries, for the microscope revealed its secrets only after Harvey died.

Blood In all animals above the corals and sea-anemones, and certain kinds of worms, there is present a circulating mass of liquid which is commonly called blood, although not all kinds of blood are alike (see pages 205–207). The blood of backboned animals has a rather complex structure, and is associated with an elaborate system of vessels and a pumping organ, called the heart.

The fluid portion of the blood is a colorless liquid, called the plasma, and consists chiefly of water. In this are dissolved various salts, organic food substances, some oxygen, some carbon dioxide, certain enzymes, and other organic substances derived from various organs and tissues of the body.

Floating in the plasma are large numbers of *corpuscles*—that is, "small bodies". The most easily seen are the so-called red corpuscles. About 3200 of these corpuscles placed side by side would stretch an inch. In addition to the red corpuscles there are also colorless bodies of irregular shape, the white corpuscles, of several distinct sizes and other characteristics. Somewhat resembling the red corpuscles in appearance are the very small colorless "platelets" (see illustrations below and opposite).

The Lymph The blood, consisting of plasma and corpuscles, fills a set of tubes which have no openings through their walls. The system is therefore called a *closed* blood system, to distinguish it from the blood systems of clams, crustaceans, and certain other animals, in which some of the blood tubes open into various spaces among the tissues. Outside the blood vessels, filling the spaces among tissue masses and cells, is a colorless liquid called lymph. It is *from the lymph* that the cells obtain their food supplies, water, salts and oxygen. And it is *to the lymph* that they discharge



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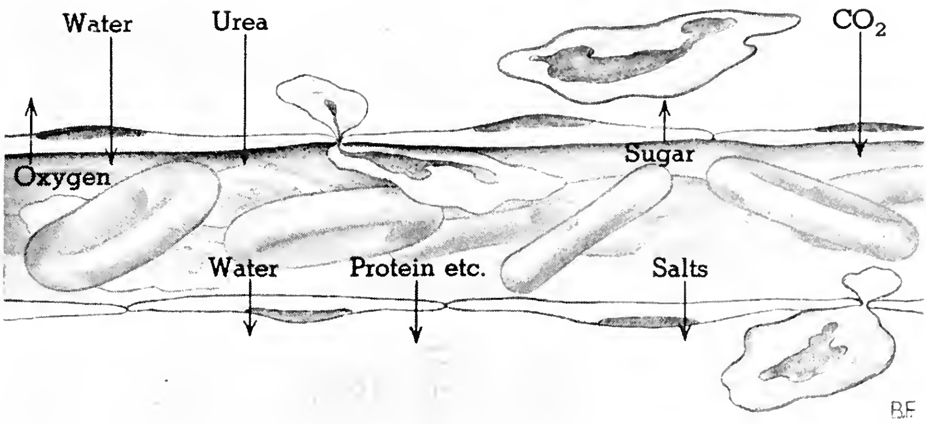
Under a microscope, human blood appears to consist of a colorless liquid with many small bodies floating in it. The more numerous particles are the disk-shaped yellowish, or "red", corpuscles, having rounded edges. Some of the white, or colorless, corpuscles, which resemble the ameba, are barely larger than the red ones, others many times as large. And there are disk-shaped platelets, much smaller than the red corpuscles

HUMAN BLOOD



BETWEEN THE BLOOD AND THE LYMPH

From the blood within the capillary, water, salts, food and oxygen pass out by osmosis. From the surrounding lymph, carbon dioxide, urea and water pass into the blood. White corpuscles squeeze through the walls of the capillaries, between the cells

their carbon dioxide, urea, and other wastes. The lymph and the blood communicate by osmosis through the walls of the smallest blood vessels (see illustration above), and by way of definite connections between lymph tubes and certain large blood vessels.

Like plasma, lymph consists chiefly of water and carries practically the same kinds of substances in suspension and in solution, although in smaller quantities. In addition, the lymph has floating in it many white corpuscles. It thus resembles blood lacking red corpuscles. The lymph has been compared in its composition to the ocean, in which life may have originated, and from which so many one-celled organisms obtain their supplies directly. The lymph is an internal ocean from which all the cells of the many-celled animal obtain their supplies.

Clotting of Blood When blood gets out of the blood vessels, it usually coagulates, or becomes thickened. The clotting is itself a solidifying of a certain protein in the plasma known as *fibrinogen*—that is, "fibrin-maker". The process is started by any injury to the lining of a blood-vessel or by contact of the blood with a foreign substance. The platelets then break down and discharge a special enzyme. This acts upon another substance in the blood and produces the actual clotting agent, thrombin, which solidifies the fibrinogen into fibrin.

If we let blood clot in a glass vessel, we can see the mass of fibers detach itself from the walls of the vessel, as the threads shrink and the clot floats at last in a clear, almost colorless or slightly yellowish liquid, called a *serum*.

The serum is practically the same as the blood plasma, lacking the fibrinogen. Whatever is characteristic or distinctive of the plasma of an individual or of a species will be found in the serum.

The White Corpuscles There are several types of white blood corpuscles, all of them resembling the ameba in consisting of naked protoplasm (see page 25). Some of them have no definite shape and move about freely and also eat like the ameba. All seem to be sensitive to chemical changes, and probably other changes, in their surroundings.

These active corpuscles are very similar in all animals that have blood. Their function has come to be understood only in modern times, chiefly through the work of the Russian biologist Ilya Metchnikoff (1845–1916), who was director of the Pasteur Institute in Paris.

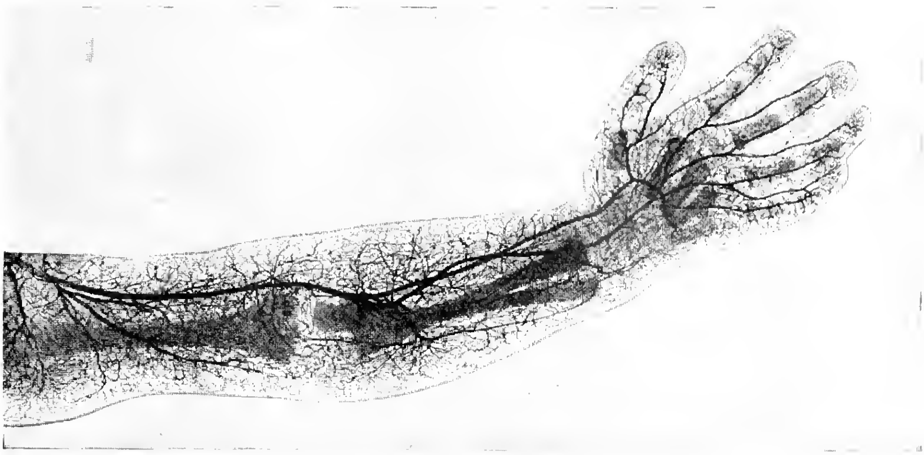
It helps us to understand the functions of these cells if we recall that whereas the ameba cell carries on *all* the functions of a living body, the various cells of a many-celled animal, like a butterfly or a baby, are *specialists.* Now the white corpuscles are in many ways the least specialized cells in the body. They have the *general* qualities of protoplasm in the greatest degree. They can move, like muscle cells. They are irritable, like nerve cells. They are chemical laboratories, like gland cells.

As *eating* cells, white blood corpuscles engulf foreign particles with which they may come in contact. For this reason, Metchnikoff called them phagocytes, that is, "eating cells". They eat and digest the dead particles that result from the breaking down of tissue cells. They may eat also live cells introduced from without, such as bacteria (see page 177).

As moving cells, the white corpuscles wander about from the lymph to the blood, or vice versa, and even into the intestines. In this way they carry with them dead matter, which is then thrown out. Or they crowd together in large numbers wherever an injury or an invasion by foreign organisms takes place. If an infection is severe, vast numbers of young phagocytes, which originate in the red bone marrow, swarm into the circulating blood. In exceptional conditions the number in the blood increases to three and four times the normal number. From the "blood count" physicians often judge the severity of an infection.

Pus is formed in a wound by the conflict between the white blood corpuscles and bacteria. Bacteria destroy some of the corpuscles. Corpuscles liberate a protein-digesting enzyme called *trypsin*, which digests dead bacteria and any body cells that may be killed by the bacteria.

Some of the other white corpuscles appear to take part in the healing of wounds and the repair of injured tissues. These originate in lymphatic tissues. Because of their peculiar behavior in the presence of foreign substances and particles, we have come to think of the white corpuscles as important agents in keeping the body in health.



Courtesy of Johns Hopkins *Bulletin* and Dr. Eben C. Hill

BLOOD VESSELS REACH ALL PARTS OF THE BODY

If we could see the arteries and veins in any living animal, with the connecting capillaries, the entire mass would practically correspond to the entire body. An X-ray picture of a baby's arm, showing the arteries

The Red Corpuscles The color of the blood is due to a yellowish pigment called hemoglobin. This readily combines with oxygen and gives it up again, according to the chemical conditions to which it is exposed. For this reason the red corpuscles play an important role in breathing (see page 205).

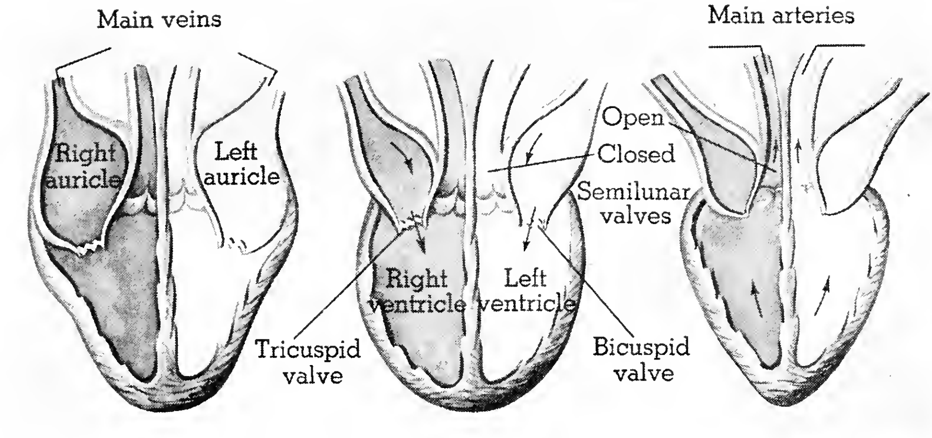
Red blood cells originate by cell-division from special cells in the red marrow of bones, which occurs in the ribs, the vertebrae, and in the upper ends of the armbone and thighbone. In the embryo, red corpuscles originate in the liver and in the yellow marrow of the long bones. Each corpuscle starts out with a nucleus. But among the mammals this soon disappears. The older corpuscles in the mammals go to pieces, and their hemoglobin is taken up by the liver and converted into part of the *bile* (see page 168).

The largest red corpuscles are found among the amphibians. Even with the low power of a microscope we may easily see the elliptical disks in the flowing blood of a frog's web or a tadpole's tail.

How Is the Blood Circulated?

The Heart and the Vessels[1] The blood is kept moving by the rhythmic contractions of the pumping organ, the heart. Blood comes *into* the heart through vessels which are called veins; blood flows *out* of the heart in tubes known as arteries. The arteries branch and divide again and again, reach-

[1]See Nos. 1, 2 and 3, pp. 198–199.



THE HEART A DOUBLE ORGAN

The two auricles receive blood at the same time from veins. Blood passes from the auricles to the ventricles, through valves that prevent flow in the opposite direction. The two ventricles discharge blood at the same time into the main arteries, through the semilunar valves, which keep blood from returning when the ventricles expand

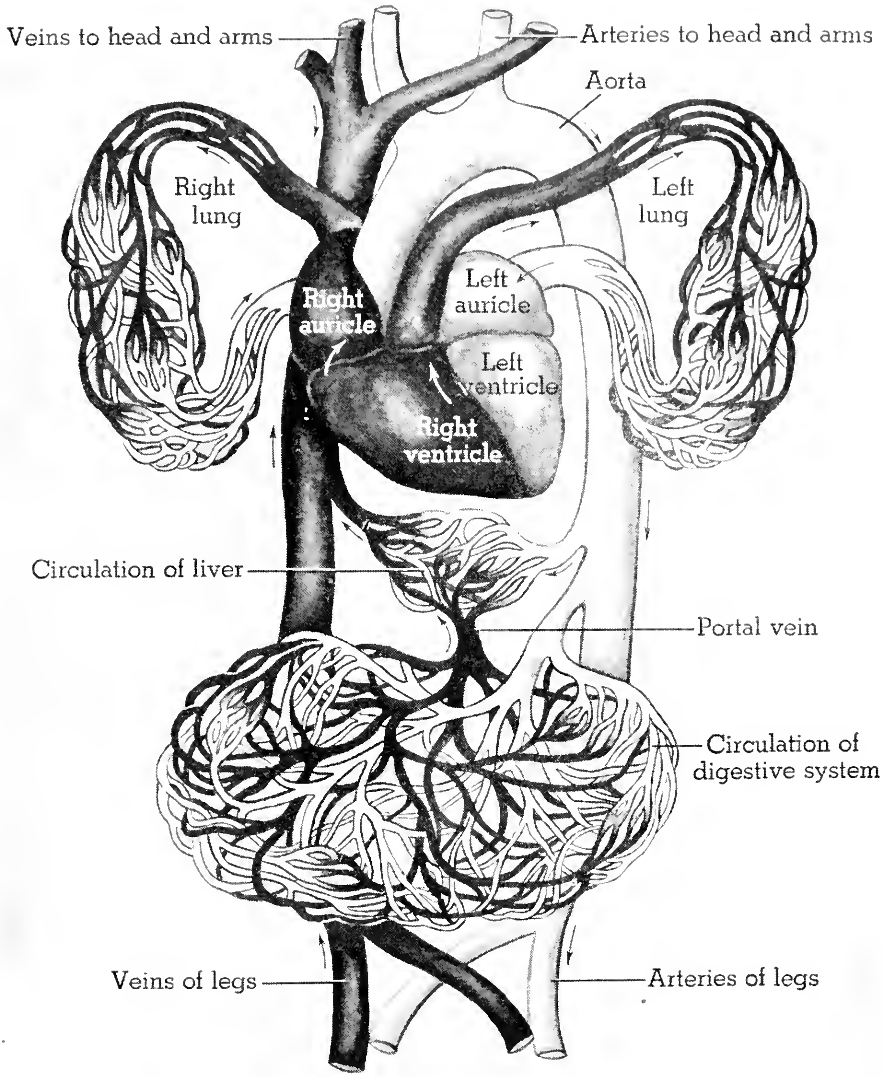
ing all parts of the body. The smallest branches, the capillaries, form a network and combine into larger and larger tubes—the veins. The capillaries thus carry the blood over from the arteries to the veins. The capillaries were first seen by the Italian Marcello Malpighi (1628–1694), who was born in the very year that Harvey published his book on the circulation of the blood, and who solved Harvey's puzzle—*How does the blood complete its circuit?*

Among warm-blooded animals (birds and mammals) the heart is a double organ. Each half of the heart consists of an *auricle*, or receiving chamber, and a *ventricle*, or pumping chamber (see illustration above). Blood cannot pass directly from either side to the other.

The *left heart* is somewhat larger and stronger than the right heart. Its ventricle contracts at fairly regular intervals, forcing the contained blood into the largest artery of the body, the *aorta*. Branches of the aorta carry the blood on to the various organs and tissues of the whole body. The auricle of the left heart receives blood from a large vein into which blood gathers from the capillaries *of the lungs*. A set of valves between the auricle and the ventricle keeps the blood from flowing back when the ventricle contracts. Another set of valves prevents the blood from flowing back from the aorta when the ventricle expands again.

The left heart thus pumps blood received from the capillaries of the lungs into arteries reaching to all parts of the body.

The auricle of the *right heart* receives blood from two large veins, and



THE CIRCULATION OF THE BLOOD

Blood from the capillaries of the stomach and the small intestines is carried by the portal vein and through the capillaries of the liver before it goes back to the heart. That is, the blood here goes through two sets of capillaries on the way from the left heart to the right heart

passes it into the ventricle, or pumping chamber. The right ventricle pumps blood into the large *pulmonary* artery, which carries it to the capillaries of the lungs. As with the corresponding chambers on the left side, a valve prevents the backflow of blood when the right ventricle contracts or expands.

The right heart pumps blood received from all over the body to the capillaries of the lungs.

The "Double Circulation" The blood-stream courses from any point and back to the start only by passing through *both* sides of the heart—that is, through both the *pulmonary*, or lung, circuit and the *systemic*, or body, circuit (see illustration, p. 191).

This "double circulation" of all warm-blooded animals makes possible a rapid exchange of carbon dioxide for oxygen. In the human body all the blood passes through the heart (and therefore through the capillaries of the lungs) once in from twenty-three to thirty seconds. The exchange of gases between the air sacs of the lungs and the capillaries is by osmosis (see page 208).

Changes in Circulation In the frog and some of the reptiles there is only one ventricle, so that the heart pumps a mixture of oxygenated blood from the lungs and deoxygenated blood just returned from the other organs. There is a suggestion of this condition in the unborn baby.

In the unborn human baby the blood from the pulmonary artery is short-circuited directly into the aorta, and from the right auricle into the left auricle, without passing through the lungs—which have of course not yet started to operate. At birth the opening between the pulmonary artery and the aorta ordinarily closes at once; the opening between the two auricles, within a few days. Occasionally, however, these passages do not close normally. The baby is bluish, for some of the blood is not aerated in the lungs. A "blue baby" often survives, but only if these "short-circuits" close.

Changes in the Blood While in the capillaries of the various tissues of the body the blood absorbs from the surrounding lymph carbon dioxide, urea, and other substances that are present in relatively large proportions. By osmosis it also loses food materials, salts, oxygen and enzymes that are relatively more abundant in the blood than in the surrounding liquids. In certain parts of the body additional changes take place in the composition of the blood. In the kidneys much of the urea, salts, and other waste substances is removed from the blood.

In addition to furnishing the cells of the body with a uniform supply of materials, the blood in its circulation tends to equalize the temperature of the body tissues, much as the circulating water in a car's radiator cools the engine. Among all living things, birds and mammals have the most delicately balanced internal fluid media.

Lymph taken from a healthy body is an excellent medium for the growth of living cells of many kinds. Inside the body of a mammal or bird, with its "warm" interior, the conditions would seem to be ideal for the growth and activities of protoplasm. But those ideal conditions cannot remain ideal very long. As the blood and lymph move rapidly through the

body, many kinds of material are constantly diffusing into and out of the stream. A cell absorbing food is moment by moment reducing the supply for itself, as well as for its neighbors. It is at the same time poisoning the lymph with its wastes and other products of its metabolism. The environment must be a constant source of needed supplies, if life is to continue. But if the environment remains constant, life cannot continue.

How Does the Blood Maintain Its Stability?

The Steadfast Blood[1] In spite of the physical and chemical changes going on in it all the time, the blood of animals, especially of warm-blooded ones, is remarkably stable. This constancy of the blood has been called *homeostasis*—standing or remaining the same. Homeostasis is not, however, a static fact or a fixed condition. It is rather a complex process; indeed, it is a living process, remaining "the same" only because it is constantly changing.

Homeostasis is attained not by preventing changes, or by insulating the blood against all happenings, inside and outside the body. It is attained by making adjustments that neutralize alterations or compensate for them. Chemical changes in the blood, for example, mean an increase in the proportions of some substances and a decrease in the proportions of others. Or they mean greater acidity or less, or the appearance of new substances. The blood meets such changes, in general, by removing surpluses and by replenishing deficits.

The circulation itself is a factor in bringing about uniformity, since it stirs up and so redistributes the contents. In addition, however, the structure of the blood, the nervous system, and special "glands" interact in ways that bring about compensations and adjustments from moment to moment.

Excesses and Deficiencies We are familiar with many adaptive processes that help to keep the blood stable. It is not always clear, however, just how the adjustments are brought about. What is the connection, for example, between sweating and getting warm? Or between feeling hunger and running short of nutrition? How does running make one out of breath?

When the quantity of a particular substance increases in the blood, some of it diffuses into the tissue spaces by osmosis (see page 87). If the proportion of this substance diminishes, some of the relative excess in various tissues diffuses back into the blood. Through osmosis relative excess or shortage becomes equalized. Surpluses removed from the blood-stream may remain temporarily in the spongy network of connective tissue under the skin, and around muscle fibers. Such "temporary storage" in tissue spaces has been compared to the merchant's practice of displaying on his shelves

[1]See No. 4, p. 199.

Summary of the Principal Changes in the Blood[1]

MATERIALS IN BLOOD	FROM	TO
Water	Digestive tract Body cells, where it is formed by the oxidation of food Reserve in tissues	Kidneys Sweat glands Lungs Tissue cells Storage in tissues
Sugar	Digestive tract Surplus stored as glycogen in liver	Storage as glycogen in liver Oxidation in body cells
Fat	Digestive tract Surplus stored in adipose tissue	Storage in adipose tissue Oxidation in body cells
Amino-acids	Digestive tract Surplus stored in liver	Storage in liver Growth of new tissue Oxidation in body cells
Mineral matter	Digestive tract Surplus stored in tissues[2]	Growth of new tissue Storage in tissues Kidneys Sweat glands Digestive glands
Vitamins	Digestive tract Surplus stored in tissues[3]	Use in body cells Storage in tissues Kidneys
Oxygen	Lungs	Oxidation of food in body cells
Carbon dioxide	Body cells through oxidation of food	Lungs
Lactic acid	Muscles during vigorous exercise Temporary storage as sodium lactate	Oxidation to carbon dioxide or conversion to glycogen Temporary storage as sodium lactate Kidneys as sodium lactate
Nitrogenous wastes	Body cells through wear and tear	Kidneys
Hormones	Ductless glands	Use in body cells Kidneys
Red corpuscles	Cells in marrow of bones[4] Surplus stored in spleen	Removal in liver Storage in spleen
White corpuscles	Cells in marrow of bones[5] Migration from tissues	Removal in liver Injuries to skin as pus Migration into tissues

[1]Adapted from N. Eldred Bingham, *Teaching Nutrition in Biology Classes*, p. 18. A Lincoln School Research Study, Bureau of Publications, Teachers College, Columbia University, 1939.

[2]Calcium and phosphorus are stored as calcium phosphate in crystals formed inside the spongy tissue of the long bones.

[3]Vitamins A and D are stored in the liver; vitamins B and G are stored in the liver and in muscle tissue; vitamin C is not stored in the body.

[4]Human blood normally contains about 5,000,000 red cells per cubic millimeter.

[5]Human blood normally contains 7000 white cells per cubic millimeter; their proportion is as 1 : 700 red cells.

and counters a fairly uniform assortment and storing part of his wares out of sight.

Sometimes surplus materials accumulate in special cells or tissues, in a relatively insoluble state. When there is an abundance of calcium, for example, the excess is deposited in small spike-shaped structures, or *spicules*, inside the long bones. When the intake of calcium is meager, these spicules disappear, being apparently dissolved and redistributed. Fats and proteins, like calcium, are also stored by being segregated in special regions.

Such segregation of "reserve" material is in some ways like the storage of reserve carbohydrates in underground parts of plants; that is, it seems to be regulated by osmosis and by the action of enzymes. Some of these enzymes condense soluble substances into colloids or insoluble forms, and some "digest" the reserves into crystalloid forms. In more complex animals, however, the storage of reserves (as well as their later release into the circulation) is largely regulated by the nervous system and the "ductless glands" (see pages 302–304). The nerves and glands are set working, however, by chemical changes in the blood.

Overflow Another way in which the materials in the blood are kept constant is through excretion, or overflow. Waste substances that get into the blood from the active tissues are normally removed by the lungs, the kidneys, and the sweat glands (see pages 216–218). If such substances became too concentrated in the blood or lymph, they would be reabsorbed by the cells and there act as poisons. But an excess of sugar, salt, vitamin C, and other substances may be discharged through the kidneys. An excessive intake of water is compensated by an increased flow of urine or by increased sweating: the blood does not become perceptibly diluted. Similarly, excessive amounts of carbon dioxide in the blood are quickly removed by the increased ventilation of the lungs and an overflow of carbon dioxide into the lung sacs.

Under normal conditions only wastes are excreted. Needed reserves may be excreted during certain diseased conditions, however. In diabetes, for example, valuable sugar overflows through the kidneys and is lost in the urine. In other conditions the calcium reserve is lost.

Hunger and Intake Maintaining the stability of the blood requires not merely removing excesses, but also ensuring suitable intake. Chemical changes in the blood due to deficiencies in nutrients or in water act upon the nerves and upon ductless glands. Feelings of "hunger" or of "thirst" arise in higher organisms, and these "feelings" influence the further conduct of the organisms—specifically with respect to food or drink. Having an appetite or being thirsty does not, of course, ensure getting what the organism needs. But these conditions are parts of the adaptive behavior of organisms, and they are related to the constancy of the blood.

Faster and Slower[1] Organisms are continually generating and losing heat. When the internal temperature rises in our own body, the blood vessels of the skin dilate. More warm blood flows to the body surface, and more heat is lost by radiation. If the rise in temperature continues, sweating and panting cool the body by evaporation.

On the contrary, if the surface is chilled, the blood vessels of the skin become constricted. If cooling continues, a secretion from a ductless gland (the adrenal) is discharged into the blood; and this induces more rapid oxidation and so increases the heat.

The so-called goose-flesh that results from chilling the skin corresponds to the "hair-raising" sometimes observed in dogs and cats and other mammals, and to the fluffing out of feathers in birds. This reaction increases the air insulation between the body surface and the cold environment.

Vigorous muscular activity increases the oxygen consumption of cells. At the same time the pumplike movements of the limb muscles make the blood return to the heart more quickly. The heartbeat is quickened, and with an increased quantity of blood in the heart each contraction delivers more blood. As muscular activity increases, the active cells yield more lactic acid and carbonic acid. This slight increase in the acidity of the blood stimulates a nerve center and accelerates breathing. Chemical changes similarly stimulate the secretion of *epinephrine* (see page 313), which in turn brings more sugar into the blood. As activity ceases, the composition of the blood returns to normal. If there is still an excess of acid dissolved in the blood, it is temporarily neutralized by the so-called "buffer salts"—some of the sodium compounds. If the condition of the blood swings toward the alkaline side, respiration becomes slower, and alkaline, or basic, salts are excreted through the kidneys until neutrality is re-established.

We see, then, that the blood maintains its balance both as to materials and as to processes. It draws upon reserves and eliminates or stores surpluses. It changes the rates of continuous processes. In almost every emergency changes within the body and the action of the "sympathetic" part of the nervous system maintain homeostasis, or the constancy of the internal environment.

Flying and Circulation There are situations in which the organism cannot adjust its blood system. When a dive-bomber plunges down rapidly and then suddenly turns his plane to fly upward, the blood in his vessels continues down toward his feet and leaves his brain depleted. That condition may last only a few seconds, but that is enough for a complete "blackout" or loss of consciousness. In those circumstances being unconscious for only a short time may be disastrous.

Even in ordinary flying, a rapidly moving plane making a turn banks

[1]See No. 5, p. 200.

over so much that the flier's blood goes to his feet and sometimes leaves him dazed or helpless. These situations are, to be sure, far from natural; and we shall have to find ways of meeting them artificially, instead of counting upon the heart to make all the adjustments.

Transfusions Where a person has lost a great deal of blood for any reason, his life can be saved in many cases only by replacing the loss with blood from another human being. Such transfusion has come to be a standard procedure in hospitals. There is one serious obstacle, however, to its general and immediate use. That is the fact that there are four "types" of blood that are incompatible. That is, corpuscles from a person having one type act in the blood of one of a different type like a foreign substance, and bring about a clotting. These inherited characteristics make it necessary in each case to find a healthy donor of the "same type", and that is not always possible on short notice. People who are able and willing to furnish a quantity of blood for such emergencies are commonly registered by large hospitals.

Replacing the lost blood promptly has saved thousands of lives, for it has the immediate mechanical effect of restoring the internal pressure of the blood system; in this way it re-establishes the action of the heart.

Blood Banks To be prepared for emergencies on a large scale, two devices have been developed in recent times. One is the "blood bank", or reserve of blood of each "type" preserved at low temperatures. The other is the plasma "bank", which combines the plasma of many men and women. The plasma is prepared by removing the corpuscles from the blood mechanically. In England such plasma reserves were established early in the Second World War; the contributions of all classes and races were used indiscriminately for all conditions in which the loss of blood is involved.

A further improvement, developed later in the war, is the use of dried serum. The combined serum is dried and sterilized, and measured quantities are sealed in vacuum bottles. In the field, the medical officer or nurse dissolves the dried serum in distilled water and injects the fluid into the veins of the injured person. The plasma and serum can be used for all "types" of individuals because they are free of corpuscles. Later still, however, Russian surgeons found that they could make good use of the red corpuscles which had been removed from blood in preparing the serum. In certain cases of anemia it was not sufficient to make up the lost blood with plasma: the red corpuscles were helpful in restoring the hemoglobin.

In Brief

There is a dual circulation in plants: one part carries liquids up from the roots, the other part carries food down from the leaves.

The blood of human beings and other vertebrates consists of a colorless fluid, the plasma, in which numerous red and white corpuscles float. The blood, circulating in a closed system of vessels, transports oxygen, carbon dioxide, food and wastes.

The colorless lymph fills spaces between tissue masses and between cells. This constitutes an internal fluid medium from which the cells of the body obtain their food and oxygen and into which they discharge carbon dioxide and other wastes.

When blood vessels are injured, the interaction of special substances leads to the formation of a clot; the clear liquid left by the clotting and the separation of the corpuscles is the serum.

The white blood corpuscles resemble the ameba. They wander in the body fluids and engulf foreign particles or organisms that enter the body, or particles of cells that have been destroyed.

The blood is propelled through the vessels by the rhythmical contraction of the heart.

In warm-blooded animals there is a double circulation; the left ventricle supplies the systemic circulation, and the right ventricle supplies the pulmonary, or lung, circulation.

The circulating blood distributes heat to the body extremities and equalizes the temperature of the whole body.

The stability of the body fluids, or homeostasis, is maintained by immediate and automatic compensatory responses to chemical deviations and to changes in concentration and temperature.

EXPLORATIONS AND PROJECTS

1 To observe the beating of the heart, anesthetize a rat or guinea-pig, open the ventral side, exposing the abdominal viscera, as well as the heart, lungs, and vessels of the thorax, but without cutting any of them. Note the rhythmic pulsation of the arteries, which carry blood from the heart. Observe a gradual filling of the auricles during the resting period. Note whether the heart begins a beat at one end or contracts all at once. Describe the heartbeat.

2 To study the structure of the heart and of the adjoining vessels, use a "haslet" (lungs with heart attached, as removed from animal) from a butcher shop.

Distinguish the pulmonary arteries from the pulmonary veins. Probe into the cut vessels leading into and out of the heart. Through which of these can you push a pencil? Compare the thickness of the walls of the veins and of the arteries. Lay open the side of the aorta by cutting with scissors. Note the structure of the semilunar valves.

Cut the heart open so as to expose the four valves. Compare the thickness of the auricle walls and ventricle walls. Trace the passage of the blood, as it moves through the heart, past various openings.

3 To observe the flow of blood in living tissues, watch the web of a frog's foot through a microscope, first under the 16-millimeter objective and then under the 4-millimeter objective. Note that the blood moves rapidly in some vessels, slowly in others, and that the pulsation can be seen in some but not in others. Find places where arterioles branch to form capillaries, and places where capillaries are joined into small veins. Observe the extent to which capillaries reach all parts of the tissue.

4 To demonstrate the "buffering" action of various compounds, treat solutions of "buffer salts" with measured quantities of acid and of alkali, and compare with the action of plain water.

Use (*a*) plain water as control, or basis of comparison, and make up four solutions as follows: In 200 cc of water dissolve (*b*) 1 teaspoonful of baking-soda ($NaHCO_3$); (*c*) 1 teaspoonful of dibasic sodium phosphate (Na_2HPO_4); (*d*) 1 teaspoonful of monobasic sodium phosphate (NaH_2PO_4); (*e*) $\frac{1}{2}$ teaspoonful each of dibasic sodium phosphate and monobasic sodium phosphate.

As an indicator use extract of red cabbage. (*Boil the leaves* in water to extract the red juice.) When acid, this extract has a pink color; when neutral a blue color; and when basic, a green color.

Prepare five sets of three containers each, using 100-cubic-centimeter beakers or small tumblers or bottles (all of the same diameter, to make comparisons of colors easier). Place 50 cc of water in each beaker of set *a*; 50 cc of baking-soda solution in each of set *b*; 50 cc of dibasic sodium phosphate solution in each of set *c*; 50 cc of monobasic sodium phosphate in each of set *d*; and 50 cc of the mixed dibasic and monobasic sodium phosphate in each of set *e*. Add 10 cc of the cabbage extract to each vessel.

Compare the colors of five sets of the solutions. Note that some are slightly alkaline, some are neutral, and some slightly acid. Record the state of each. Set up one burette with a half-and-half mixture of hydrochloric acid and water, and a second beaker with a half-and-half mixture of concentrated ammonia and water. Add acid, a drop at a time, to one of the beakers having water (a_1) until there is a pink color (two drops should be enough). Add sufficient base to the second water beaker (a_2) to give a barely green color (two drops ought to be enough). Add enough drops of acid to one of the vessels in each of the four other solutions (b_1, c_1, d_1, e_1) to give the same pink color shown by the acid water solution (a_1) and record the amount of acid each required. Record the number of drops of base required by each of the four solutions b_2, c_2, d_2, and e_2, barely to give the green color of the basic water solution (a_2). Compare the number of drops of acid and

of base necessary to shift the acidity or alkalinity in each of the solutions to the same degree as two drops did in the water solutions. Record the results in a table, summarize, and then explain what you understand by the "buffering" actions of these salts.

5 To find the effect of exercise on the pulse rate, determine the number of heartbeats per minute while at rest, and again after taking exercise. Compare the rate and the intensity of the pulse before and after the exercise.

QUESTIONS

1 Of what does human blood consist?

2 In what respects is blood like lymph? In what respects do the two fluids differ?

3 How does clotting take place?

4 What do the blood and the lymph do?

5 How is the blood circulated throughout the vessels of the body?

6 How does the heart of a frog resemble that of a man? How do the two differ?

7 What is the advantage of a "double circulation"?

8 What are the principal changes that take place in the blood?

9 How is the stability of the blood and of other body fluids maintained?

10 What compensating reactions take place when muscular activity is increased? when an organism is exposed to extreme cold?

11 How is homeostasis maintained by an acceleration of processes that are continually taking place anyway?

12 How do "buffer salts" tend to preserve the alkalinity of the blood?

1 Do plants breathe, as well as animals?
2 What makes a fish die when it is taken out of water?
3 What makes men drown where fish thrive?
4 How do frogs breathe without a diaphragm?
5 How do fish breathe?
6 Have whales lungs, or do they breathe like fish?
7 How do the cells in the roots of water plants get oxygen?
8 How do animals in deep water breathe?
9 How do clams breathe when they are buried in the sand?

The simplest plants and animals get their oxygen directly from the surrounding air or water and discharge their carbon dioxide directly to the surrounding medium by osmosis. Here respiration and oxidation are close together in space and in time. But in more complex plants and in animals, as in man, there is sometimes a considerable separation between the two processes.

The respiration of simple organisms, and the internal respiration carried on by the cells of higher organisms, are very much alike, since the body cell lives in a liquid medium, as does the ameba in the pond. But how do the various complex plants and animals get oxygen and excrete carbon dioxide? Do all the organisms that live in water get their oxygen directly from the water? How do the innermost parts of large plants and animals get air?

How Do Cells Obtain Air?

Gas Exchange of the Cell[1] Plants and animals consisting of single cells absorb gases from the surrounding air or water by osmosis. And gases are removed from such cells by osmosis, diffusing into the surrounding air or water.

In large, many-celled organisms air reaches the living cells either by diffusing through special spaces, as in plants, or through special tubes, as in insects (see page 16). Or it travels in a solution (blood) that reaches all parts of the body (see page 186, and illustration, p. 202). In every case, then, the protoplasm of the individual cell (1) gets its oxygen from its immediate neighborhood, and (2) discharges its carbon dioxide and other products of oxidation into its immediate surroundings.

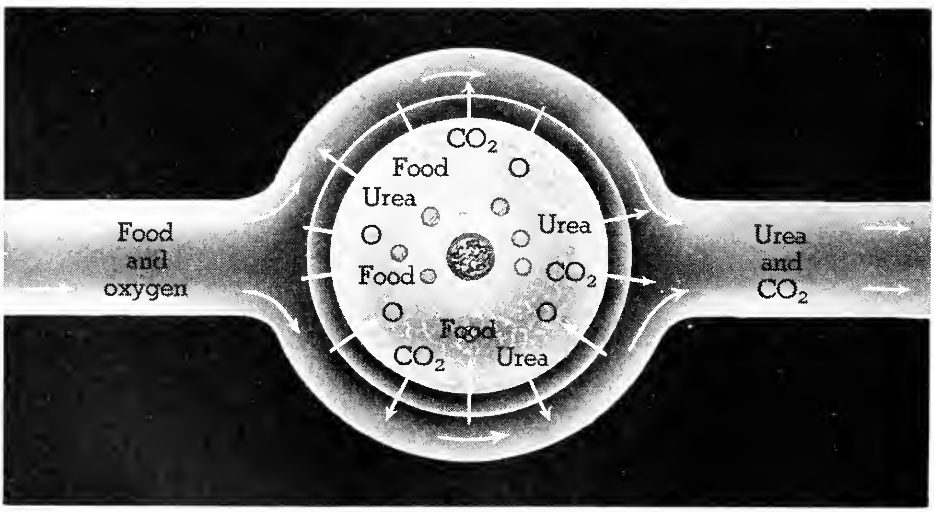
In the interior of a leaf air constantly circulates through the air-spaces among the cells. Gas exchange between the various cells and the surround-

[1]See Nos. 1, 2 and 3, p. 212.

ing space also takes place by osmosis through the cell walls. If we think of the ingoing and outgoing gases, and disregard the chemical changes in which the gases take part, we may speak of this process as respiration, or breathing. Stomata in the epidermis, or skin, of young twigs connect with the intercellular spaces below the surface (see illustration, p. 142). In the older twigs, however, in which bark-formation has been going on for some time, the live cells beneath the bark get their oxygen supply by way of the *lenticels*. The comparatively small amounts of oxygen used by the plant cells diffuse slowly into them from air in these openings and passages. The carbon dioxide from the cells diffuses to the exterior along the same paths.

In most plants the stomata, or breathing holes, are located on the under side of the leaf. In water-lily pads and similar floating leaves, these openings are on the upper surface, where they are exposed to the air. In some plant species, variation in leaf structure seems definitely related to respiration. Leaves exposed to air "breathe" through stomata, whereas submerged leaves carry on gas exchange by osmosis through the general surface.

Respiration in Roots The roots of most familiar plants and staple crops, with the exception of rice, absorb oxygen dissolved in the moisture on the outer surfaces, and also give out carbon dioxide by osmosis. Most roots suffocate when the water table is too high—that is, when the free



INCOMES AND OUTGOES OF A LIVING CELL

In the body of one of the larger or more complex animals, each cell receives oxygen, as well as food, by diffusion from the surrounding fluid. Each cell discharges into this surrounding fluid carbon dioxide, as well as urea and other products of metabolism—also by diffusion through the cell wall. The fluid, or lymph, communicates in turn with the blood stream

LEAVES IN AIR AND IN WATER

The deeper the leaves of the water crowfoot are submerged, the more divided up they are. For a given amount of tissue, finely divided leaves have a greater absorbing surface. Pondweeds and arrowheads bear broad leaves in the air and long ribbon-shaped leaves in the water

water filling the soil spaces keeps the roots submerged too long. The roots of rice are fine and threadlike, exposing much surface through which an adequate supply of oxygen is obtained from the surrounding water.

If the water table is near the surface as after prolonged rains in the early summer, corn roots, for example, do not penetrate very far into the soil. Then if a drought follows, the crop suffers badly, for the shallow root-system cannot reach the lower water levels, and the plant quickly dries out. On the other hand, when the early summer is exceptionally dry, the young roots grow deeper, so that a prolonged drought later in the season is not so destructive. Alfalfa will not thrive in a soil that is not well drained, for the roots "drown".

Plants growing in swamps, where the level of the water is rather constant, have shallow root-systems; and they breathe through the portions that extend above the water.

Breathing in Man[1] The lungs are soft bags consisting of air-tubes and air-sacs, which are lined by a layer of thin-walled cells and surrounded by very fine blood vessels. They are suspended in the thorax, or chest cavity, and air comes into the air-sacs of the lungs, and also passes out, by way of the windpipe, or *trachea* (see illustration opposite). The trachea divides and branches again and again into the *bronchial* tubes. While the air-sacs are filled with air, oxygen diffuses from these spaces into the lymph and blood of the surrounding vessels, and carbon dioxide diffuses in the opposite direction (see illustration, p. 208).

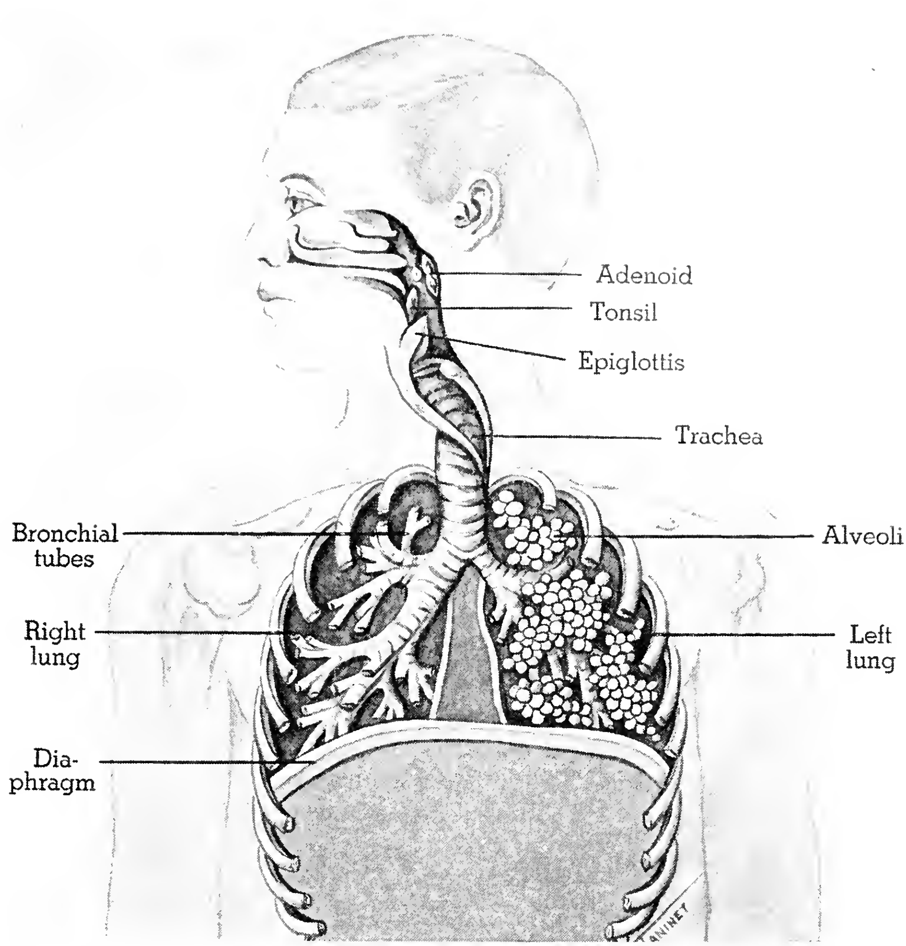
The lungs are filled with fresh air and emptied again by the action of (1) muscles attached to the ribs and (2) a large muscular organ called the

Rutherford Platt

BREATHING ARMS OF SWAMP PLANTS

In cypress trees, which are typical swamp plants, the roots breathe through the so-called "knees", which rise above the level of the water. The roots of many trees spread out, as in the tamarack, soft maple, pin oak, spruce, hemlock, and cedar. In drier soil they form deeper roots; in swamps they spread roots near the surface. Trees that form tap-roots, such as hickory and ash, are never found in swamps

[1]See Nos. 4, 5, and 6, pp. 212–213.

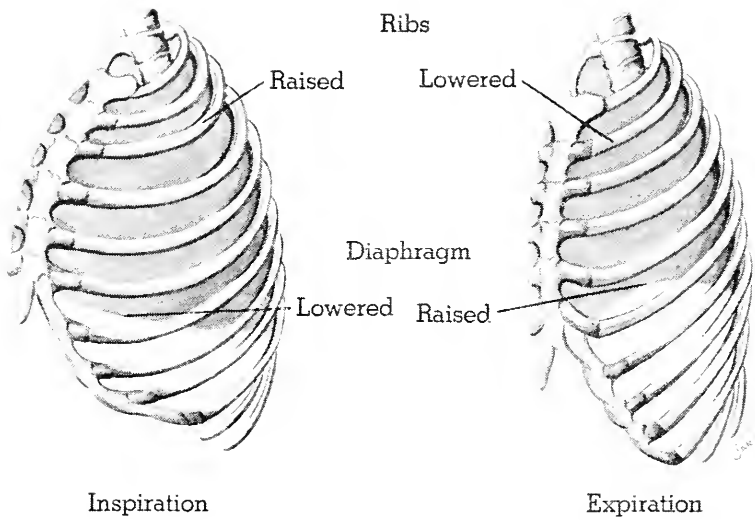


LUNGS IN MAN

The main windpipe from the throat divides into main branches, the bronchi, one to each lung. The bronchi divide again and again, the smallest air tubules ending in the alveoli, or tiny sacs. The epiglottis drops over the trachea when food is being swallowed from the pharynx to the esophagus

diaphragm. This separates the chest cavity from the abdominal cavity (see illustration above). Inspiration and expiration are caused by the alternate expansion and contraction of the thoracic cavity.

Blood-Red We have seen that the circulating blood takes part in distributing oxygen and carbon dioxide, as well as foods, wastes, and other substances. And that the actual oxygen-carrier is the yellowish hemoglobin of the red corpuscles, since it combines readily with oxygen, forming oxyhemoglobin (see page 189). When oxygen is relatively scarce, it gives up oxygen.



BREATHING MOVEMENTS IN MAN

When the diaphragm, the muscular partition between the thorax and the abdomen, is pulled down, the chest cavity enlarges. When the ribs are raised, the chest also expands, and air comes in through the windpipe. The rib muscles and the diaphragm normally work in unison. When these muscles relax, the chest cavity contracts and forces out the air in the lungs

This taking on or putting off of oxygen seems to depend upon the relative quantity of oxygen, and is a "reversible" reaction, as shown in this equation:

$$\text{Hemoglobin} + \text{oxygen} \rightleftarrows \text{oxyhemoglobin}$$

When blood reaches tissues far from the oxygen supply, the reaction moves to the left. In the vicinity of the lung (or other respiratory organ) the change moves to the right. When the blood contains much oxyhemoglobin, it is bright red; when little, a maroon color.

A man rowing in a race or climbing a mountain may use about one and one-fourth gallons of oxygen per minute. If he had no red blood corpuscles, it would be necessary to circulate 375 gallons of fluid each minute to supply this amount of oxygen.[1]

[1]Actually, there is but about one and a half gallons of blood in the body. At this rate all the blood would have to rush round the body 250 times a minute, or about four times each second. Obviously, no human heart could sustain such a load. One gallon of blood with hemoglobin carries as much oxygen as 60 gallons would without it. It takes about 300 gallons of water at body temperature to dissolve one gallon of oxygen.

The plasma of the blood, like the water of the sea, carries in solution varying amounts of the atmospheric gases. Ordinarily, these seem to make no difference. When men are exposed to high atmospheric pressures, as in deep tunnel work or in deep diving, the amount of nitrogen in solution seems to increase. On returning to the surface, nitrogen bubbles out of the blood and expands in the capillaries. That results in a very painful and sometimes fatal condition known as the "bends". It is possible to prevent that by having the workers come back to normal air pressure very slowly, through so-called "decompression chambers". A similar difficulty arises in aviation when airplanes are brought rapidly from the surface to very high altitudes, where the air pressure is very low: here again the nitrogen may "boil" out as bubbles. It is customary to prepare aviators who are about to make high ascents by having them spend some hours in low-pressure chambers, where they can breathe the needed amount of oxygen and slowly eliminate some of the nitrogen dissolved in the blood.

Another problem arising out of high flying is the impossibility of breathing in and distributing enough oxygen at the highest levels, where the air is so very "thin". Aviators are supplied with special masks, through which needed amounts of oxygen are delivered from flasks or tanks.

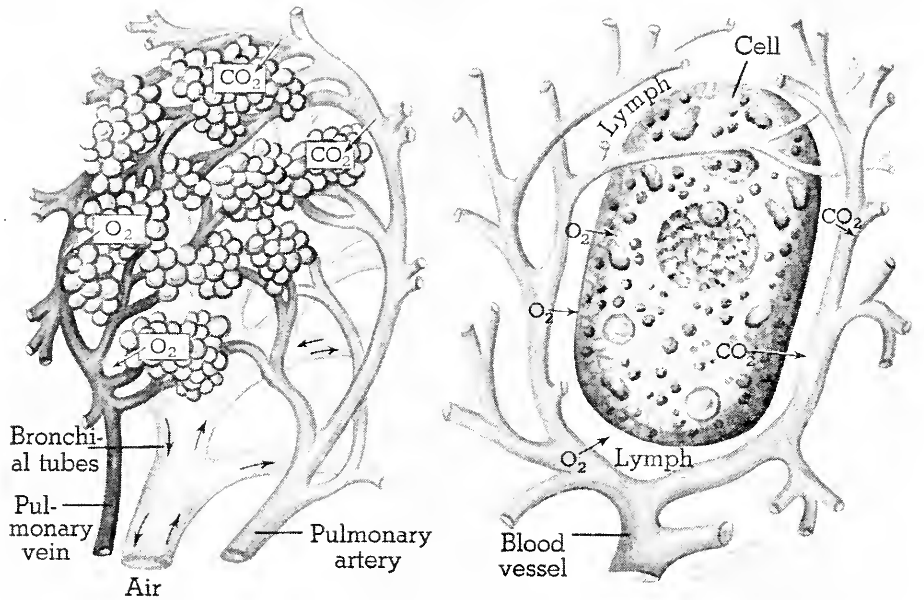
Many persons find that merely going to the mountains, not to mention flying up into the air several miles, puts too much strain upon the heart. And those who always live in high mountains have relatively larger hearts than those who dwell at the seashore.

Strange as it may seem, the real blue bloods of the animal kingdom are cold-blooded arthropods, not man. In crabs, lobsters, and the like the blood contains *hemocyanin*, a pigment in which the metallic element is copper. Hemocyanin turns blue when it combines with oxygen, and is colorless in the absence of oxygen. It is not carried in special corpuscles, but dissolved in the body fluid.

In all animals that have blood, cell respiration is related to the blood. That is, the cells get their oxygen from the blood, and they discharge their carbon dioxide to the blood. In all such animals we therefore apply the term *respiration* to the process by which the air is brought from the outside to the blood, and by which the carbon dioxide is thrown out.

Air-tubes[1] Insects use relatively large amounts of oxygen. Movements of the body compress and release the delicate branching air-tubes, which reach all parts, thus aiding in the circulation of air (see illustration, p. 16). In some insects, as the common locust, rhythmic movements alternately empty and fill the air-pipes, and so accelerate the diffusion of oxygen and the removal of carbon dioxide.

[1]See No. 7, p. 213.



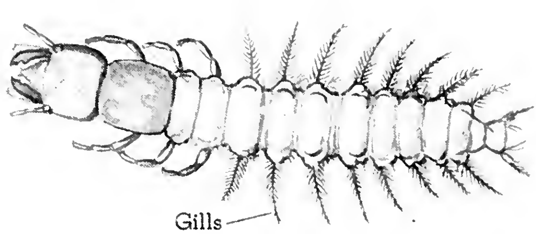
EXTERNAL AND INTERNAL RESPIRATION

The external respiration consists of all the processes that bring oxygen to the several millions of cells in the body, and remove from them the carbon dioxide which they excrete. The internal respiration consists of the gas-exchange between any body cell and the surrounding lymph. The external respiration thus includes the muscular activities of pumping air into and out of the lungs; the actual movement of air into and out of the lungs; and the osmotic movements of oxygen and carbon dioxide between the air sacs and the blood, and between the blood vessels and the lymph

Gills[1] The simplest kind of blood respiration is found in such animals as the earthworm. In this, the respiration takes place by osmosis through the moist epidermis, or skin. In some worms there are extensions of the skin surface into little outgrowths, called *gills.* In clams and oysters there are special outgrowths that multiply the breathing surface in much the same way (see illustration opposite). We may think of the gills in lobsters, crabs, and other water animals as structures in which the blood is brought close to a great expansion of surface within a comparatively small space.

Although insects are in general "air-breathers", some make their abode in water for at least a part of the life cycle. The diving beetle comes to the surface and takes down a supply of air under its wings. So does the water boatman. Mosquitoes, in the larval and pupal stages, live in water; they get

[1]See No. 8, p. 213.



Some water insects breathe air from above the water surface through special openings into the tracheae. The hellgrammite and a few others breathe through leathery gills, which expose relatively large surfaces to the water

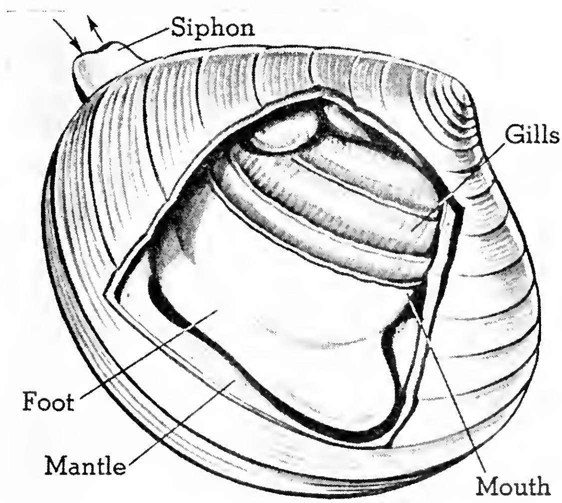
A WATER–BREATHING INSECT

air at the surface of the water through special breathing tubes. The "hellgrammite", the larval stage of the Mayfly and of the Dobson fly, has projecting gills, through which air is absorbed from the water.

Life without Air A few species generate energy without a supply of oxygen. In yeast and in certain other simple plants, ferments, or enzymes, bring about the breakdown of carbohydrates into simpler compounds, as alcohol and carbon dioxide, *in the absence of oxygen.* Such organisms are called *anaerobic*, that is, living without air. The release of energy from complex chemical compounds without oxidation may be likened to the release of energy that results from the collapse of a structure when a particular small detail is disturbed.

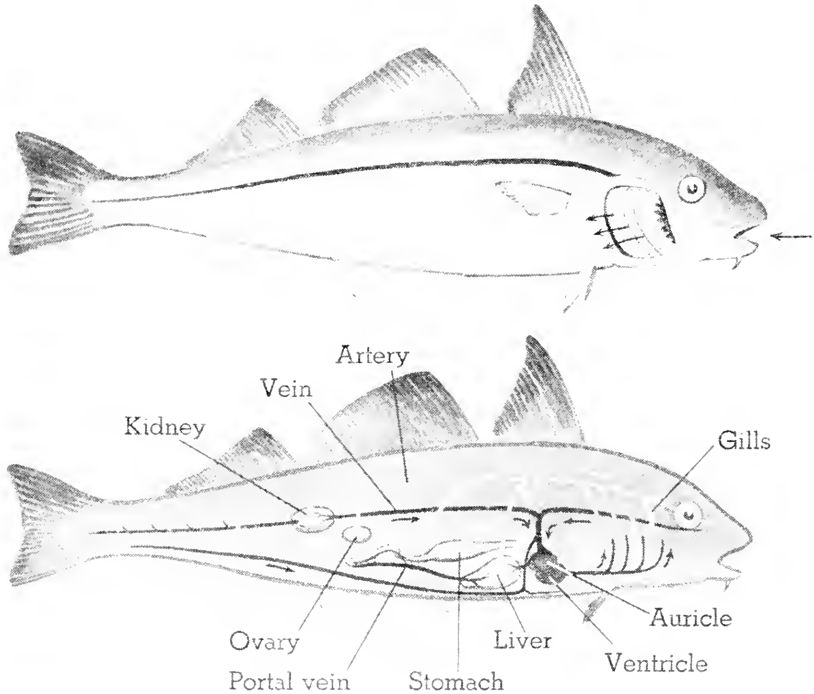
Breathing in the Vertebrates[1] All the backboned animals, except the fishes and the young stages of amphibians, breathe by means of lungs. In the fishes, water with oxygen in solution is taken into the mouth. But

Water inside the clam's shell is kept in constant circulation by the vibration of cilia which cover the whole surface of the body, the lining of the mantle, and the surfaces of the gills. The water also passes through tiny openings in the gills themselves. As the water passes over the gill surfaces, gas-exchange takes place between the flowing water and the blood circulating inside the gills. Water comes into the mantle cavity and is discharged again through the siphon



HOW THE CLAM BREATHES

[1]See No. 9, p. 213.

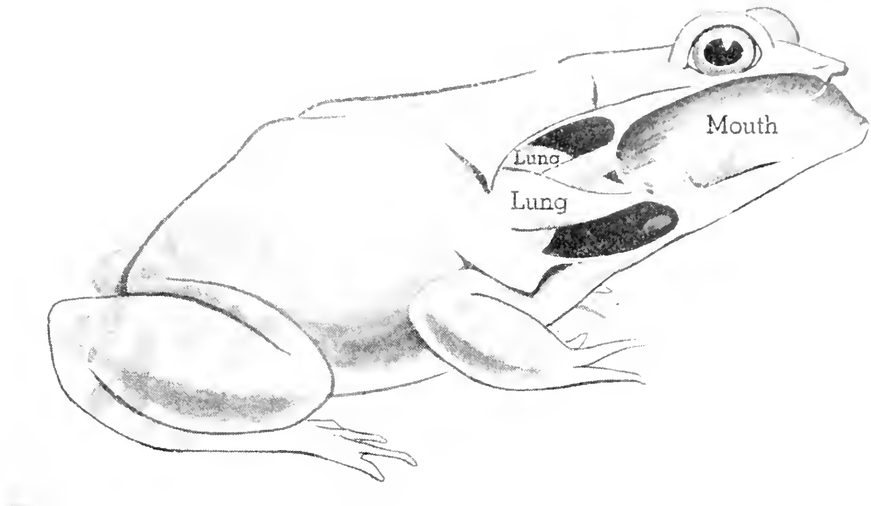


HOW FISH BREATHE

Water taken in by the mouth passes over the gills and out again, as indicated by the arrows. The fish has one auricle and one ventricle. The heart pumps the blood gathered from the body to the gills, in which gas-exchange takes place. The oxygenated blood is gathered into arteries: one main branch goes forward to the brain and head, the other goes backward toward the rest of the body

instead of being swallowed into the gullet, the water passes out through a series of openings in the sides of the throat and over the gills (see illustration above). In the sharks the gills slits are open to the exterior; in bony fish they are covered by a plate with a free edge toward the rear. The gills are fine, feathery structures containing many delicate blood vessels, and are arranged on arches, four on each side of the pharynx. As the water passes over the gills, the oxygen in solution diffuses into the blood from the surrounding water.

Among the amphibians the adults swallow air into the lungs. The young, however, have moist skin and gills through which gases diffuse between the lymph and the surrounding water. Adult frogs differ from toads in having moist skins and in being able to live under water for considerable periods of time.



HOW THE FROG BREATHES

The frog swallows air into the lungs. Lowering the floor of the mouth enlarges the mouth cavity, and air comes into it through the nostrils. The nostrils are closed, and the floor of the mouth is raised. The air is thus forced into the pipe leading to the lungs. If the frog were forced to keep his mouth open, he would suffocate

Reptiles and all the higher vertebrates breathe entirely by means of lungs. Reptiles swallow air, as do the amphibians. Birds rely solely on rib movements, as they have no diaphragm. All mammals breathe like man. Water-snakes and snapping turtles spend most of their time in water, but come to the surface from time to time to breathe. Alligators and crocodiles have raised nostrils, which protrude above the water when the rest of the animal is submerged. Whales, like other mammals, breathe air in lungs.

In Brief

Living cells always exchange gases with the liquid which immediately surrounds them.

In many-celled organisms, cells remote from the surface get their oxygen supply indirectly.

Roots get oxygen that is dissolved in the soil water which immediately surrounds them. Air diffuses into the leaves and bark of plants through special openings.

Plants growing in swampy areas have shallow root-systems; roots suffocate if submerged too long or too deeply.

The hemoglobin of red-blooded animals carries oxygen; human blood carries 60 times as much oxygen as dissolves in an equal volume of water.

The oxygen-carrying substance in animals with blue blood is hemocyanin.

In all animals with blood, external respiration is the gas exchange between the blood and the outside; internal respiration is the gas exchange between the blood and the living cells.

Insects breathe by means of tracheae, or air-tubes, which open to the surface and reach the fluids in all parts of the body. Body movements compress and release these tubes, setting up air movements.

In some animals respiration takes place by osmosis through a moist skin or through gills, which are specialized skin outgrowths within which blood circulates and around which the oxygen supply moves.

Other animals breathe by means of lungs. Fresh air is brought into the lungs, and stale air is exhaled, by muscular movements. Dissolved gases pass into and out of the blood by osmosis through living membranes of the lungs and through walls of blood vessels.

EXPLORATIONS AND PROJECTS

1 To find the relation of air to plants and animals living in water, place small fish from the aquarium in two vessels, one containing ordinary tap water and the other tap water which has been cooled in a closed flask after the air has been removed by boiling. Compare results and note conclusions.

2 To show that dissolved gases diffuse through a membrane, prepare two 8-ounce widemouthed bottles as model cells (see page 88), one containing plain water, and the other water through which carbon dioxide has been bubbled for about fifteen minutes. Invert the two bottles, after the membranes have been securely fastened, in two dishes containing water. On the following day add a few drops of *pink* phenolphthalein solution to each vessel. If the indicator loses its color, the water has become acid from carbon dioxide dissolved in it.[1] Compare results and note conclusions.

3 To find out whether oxidation is accompanied by a loss in weight, compare the dry weight of equal quantities of corn or wheat grains before and after germination. Account for the results.

4 To study the structure of the respiratory tract, obtain a haslet from the butcher. Blow air into the trachea and note the expansion of the lung tissue. Compress the trachea and bronchial tubes. What holds them so rigid? Open one side of the trachea and of the main branch of the bronchial tube within one of the lungs, to show the many little openings through which small tubes carry air to and from the larger tubes.

[1]Red cabbage extract (see page 199) can also be used as an indicator.

5 To observe the effect of exercise on the rate of breathing, record the rate of breathing before and after exercise. Use a graph to show the individual variations, as well as the relation between the amount of exercise and the rate of breathing.

6 To demonstrate the effect of exercise on the excretion of carbon dioxide, compare the length of time it takes to turn a measured amount of pink phenolphthalein colorless, by exhaling through it with a glass tube before exercising, and through a similar amount immediately after exercising.

7 Examine the sides of the abdomen and the under surface of the thorax of a large grasshopper (or other insect) for spiracles, or breathing pores. Observe in a live insect at rest the body movements which would tend to move air through these holes. Dissect the animal under water and identify the air-tubes, or tracheae, which carry air to all parts of the body. Examine some of these tubes under the microscope.

8 To study the structure of gills, dissect the mouth and the gill cover of a fish, exposing the gills. Note their position with reference to water which flows through the mouth and out under the gill covers. Examine a small portion of the gill with the microscope and note its feathery texture.

9 To study the respiration of a frog, place a frog in an aquarium or large jar of water so that it cannot rise to the surface except by swimming. Note whether the frog comes to the surface to breathe. How can it carry on respiration when beneath the surface? Is there anything to show that the animal is suffering for lack of air if it is kept from coming to the surface for several minutes? Remove the frog from the aquarium and place it on a table. Watch movements of the throat and of the abdomen, and describe their relations to getting air into and out of the animal's lungs. Contrast the breathing of a frog with that of a mammal.

QUESTIONS

1 What is the source from which living cells ultimately get oxygen, and what eventually becomes of the waste gases which living cells liberate?

2 Since living matter oxidizes itself, how do animals nevertheless keep on living?

3 What different special oxygen-carrying substances are found in different species?

4 In many-celled organisms, how do cells remote from the surface get their oxygen supply?

5 What conditions within the body influence the rate of respiration?

6 How do organisms without breathing organs respire?

7 How does the breathing of the frog resemble that of the fish? How do the two differ?

8 How does the breathing of a frog resemble that of a bird? How do the two differ?

1 How does an organism come to produce substances that it does not need?
2 Are the wastes produced by protoplasm poisonous?
3 Does the excreted urine in animal manure make it injurious to plants?
4 Do plants excrete wastes?
5 What kinds of wastes are excreted?
6 Is sweat a kind of waste?
7 Have all animals kidneys?
8 How do the kidneys make urine out of wastes in the blood?
9 Why do physicians sometimes analyze a patient's urine?
10 What other organs besides kidneys remove wastes?

Living things are continually taking in food and oxygen. From the oxidation of food within their living cells they derive energy. We know that whenever fuel burns, there are formed ashes and hot gases that would smother the flame unless they were removed. Would any of the substances formed during metabolism in living organisms interfere with further metabolism? Are there any wastes produced besides the carbon dioxide and water removed by the lungs? How do living things dispose of any such wastes? How does the body remove waste fluids without losing essential food constituents?

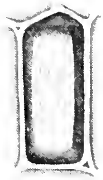
What Kinds of Wastes Are Produced in Living Things?

The Origin of Wastes in Living Things In every chemical process substances are formed that did not exist before. Some of the substances produced in the metabolism of a complex organism are related to keeping the protoplasm alive, as, for example, digestive ferments and chlorophyl. Incidentally, however, other substances are also produced, and these may be of no use to the living body or to the living process. Some may even be injurious. Such substances are *wastes*, like the sawdust of a mill or the smoke that goes up the chimney or the coal-tar of a gas factory.

Removal of Wastes from Cells Carbon dioxide, water, urea, and other waste products of oxidation in protoplasm diffuse out of cells by osmosis. Oxygen, which is one of the wastes or by-products of photosynthesis (see page 138), also diffuses out of the chlorophyl-containing cells through the cell-walls.

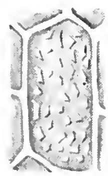
In plants, water and carbon dioxide are usually eliminated in the form of gas. The carbon dioxide discharged by the cells of the roots usually remains in solution, forming so-called carbonic acid.

Cystolith in leaf of rubber plant



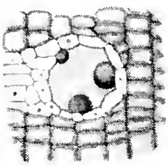
Raphides in root cell of spiderwort

Glandular hairs of geranium

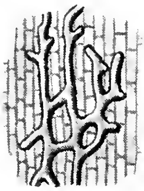


Chromoplasts in petal of nasturtium

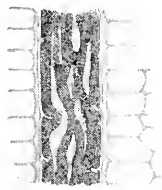
Calcium oxalate in linden phloem



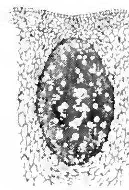
Resin in duct of pine



Latex tubes in dandelion root



Latex tubes of rubber tree



Oil gland in orange peel

Shedding of bark

Fall of leaves

Gum exuding from injured cherry tree

PLANT WASTES

Crystals and other bodies found in plant cells or in specialized ducts and spaces are often waste materials locked up out of the way of active living cells. Where such materials are accumulated in leaves and bark of long-lived plants, or even in seeds, they become removed from the plant protoplasm

Storage and Stowage in Plants The masses of starch, fat and protein accumulated in the cells of many plants are normally used by the plants themselves—unless we or some other animals take them away first. But because of their obvious share in the life of the plants, we speak of them as "stored" foods. Yet the same plants and many others accumulate in their tissues quantities of insoluble materials which they never use again. These substances are in many cases injurious to living protoplasm, although human beings have found ways of using them for their purposes. Such mate-

rials are regular by-products of metabolism which we may consider as "wastes". And they are *stowed* in plant cells, rather than stored, instead of being pushed out of the system, or excreted, much as useless rubbish is stowed away in the cellars and attics of many homes.

Excess of mineral matter absorbed from the soil is separated out of living cells and precipitated as insoluble compounds. Thus crystals of oxalate of lime are found in hundreds of species—for example, the horse-radish, the root of jack-in-the-pulpit, and other sharp-tasting parts (see illustration, p. 215).

We usually classify the most common organic wastes in relation to their possible *uses to us*, as below:

Human Uses of Organic Plant Wastes

Pigments. Direct enjoyment of color in flowers, fruits, leaves, wood, etc. Extraction of dyes for use on fabrics.

Essential oils. Direct enjoyment in fruits and flowers; spices. Extraction for perfumes, seasoning foods, candy, etc.

Gums and resins. Adhesives, waterproofing, protection of materials against insects and fungi, sealing joints.

Tannins. Chiefly for tanning leathers; drugs.

Alkaloids. Poisonous generally; used as drugs—morphin, quinin, atropin, cocain, caffein, digitalin, etc.

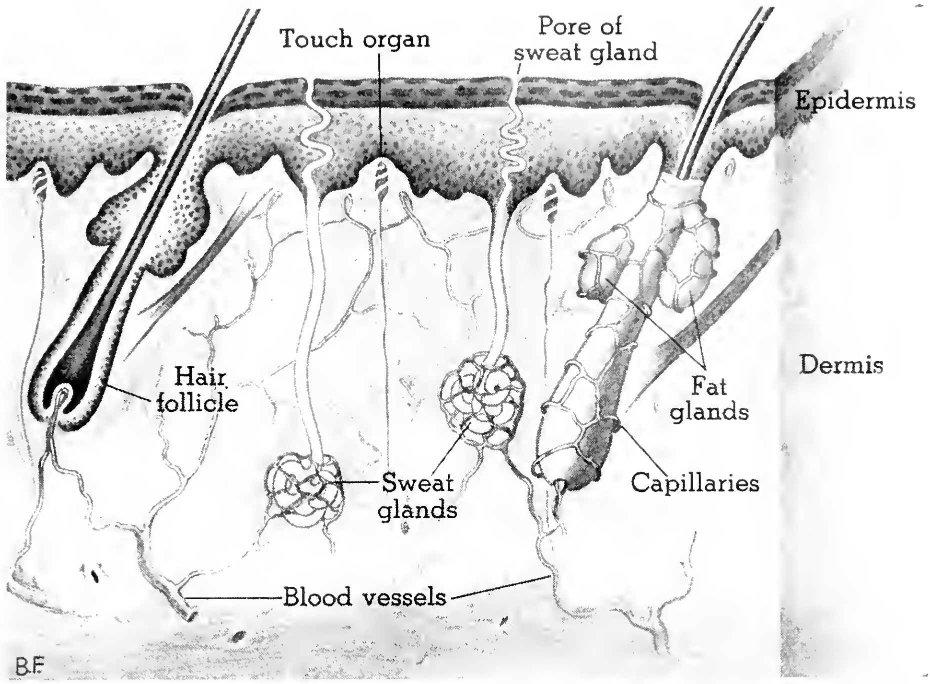
Although these waste substances are useless to protoplasm, they may be of some value to the plant as a whole, or to the species, in some special relation. Thus pigments and odors of flowers may be of use in relation to insect visits, or essential oils and tannins may be of value in protecting plants from animals and from bacteria or fungi.

Excretion in Animals To a comparatively slight extent waste products of animals are accumulated in some of the cells, like the waste products of plants. Thus some of the pigments found in animals are no doubt to be considered as wastes deposited in the cells of the skin or even in the interior of the body. Much of the lime found in the skin of such animals as the starfish and the sea lily and the coral framework of the coral polyp fall into the same class. Small quantities of lead are found in the skeletal tissues.

One-celled animals excrete their wastes just as they excrete carbon dioxide, by diffusion. In animals that have blood and lymph, wastes diffuse into these conducting fluids and for the most part are then eliminated from the body through special organs.

How Are Wastes Removed from Animal Bodies?

The Lungs and the Skin Water and carbon dioxide are excreted from the lungs, as well as small quantities of urea and possibly other organic substances (see page 187). A certain amount of waste gets into the intestine



SECTION OF THE SKIN

The sweat gland consists of a fine tubule opening to the surface of the skin at one end and coiled up in a knot at the other. The coiled portion is surrounded by blood vessels from which water, salts, and traces of urea are withdrawn into the gland tube. Around the base of each hair are fat glands. Sensitive nerve endings come close to the surface

directly through the lining cells, in part carried by the white corpuscles (see page 188), and in part through the secretions of the liver. From the intestine these substances are removed, together with the refuse from the food, in the feces.

Sweat is excreted by special glands which open on the surface of the skin (see illustration above). The water part of the perspiration usually evaporates as fast as it comes out of the glands, leaving a solid deposit of the wastes. When perspiration is more rapid, we can see the drops of sweat on the skin. When this dries, the solids are left on the outside of the skin, instead of in the mouths of the tubules. Ordinarily we perspire from 400 to 750 cubic centimeters daily. The sweat contains about 2 per cent of solids. Thus miners and other laborers who sweat excessively lose some of the essential materials of the body. They need to perspire freely to keep the body cool. But they need also to increase intake of water and salt to compensate for the materials lost through the sweat glands (see page 195).

The Kidneys[1] Most of the solid waste substances from body cells are filtered out of the blood by the kidneys, which are the typical excretory organs of the backboned animals.

In the human body there are two bean-shaped kidneys, each about as long as the width of the hand. They are located in the back of the abdominal cavity, one on each side of the spinal column, slightly lower than the stomach. The kidney is like a gland in structure (see page 169), a mass of tiny tubules, branched and twisted, with a complex network of capillaries. The waste substances diffuse through the walls of the capillaries into the tubules, and the fluid (urine) is gathered by these tubules into a funnel-shaped hollow (see illustration opposite).

How Do the Kidneys Separate Waste from the Blood?

The Gland Unit The kidney separates, or filters, organic wastes from the blood by a combination of osmosis and the action of special cells. The separation starts in a tangle of capillaries called a *glomerule*, embedded in a "capsule" that opens into a long, thin-walled and greatly twisted, or convoluted, tubule (see illustration, p. 221).

The process is as follows: 1. Waste substances diffuse into the capsule from the blood in the capillaries of the glomerule. 2. The wastes are carried by the tubule toward the funnel-like pelvis of the kidney, into which all the tubules empty. 3. Much of the water and some of the dissolved substances are reabsorbed from the tubules by the blood in capillaries entangled with the tubule. 4. At the end of the tubule there remains the watery solution called urine.

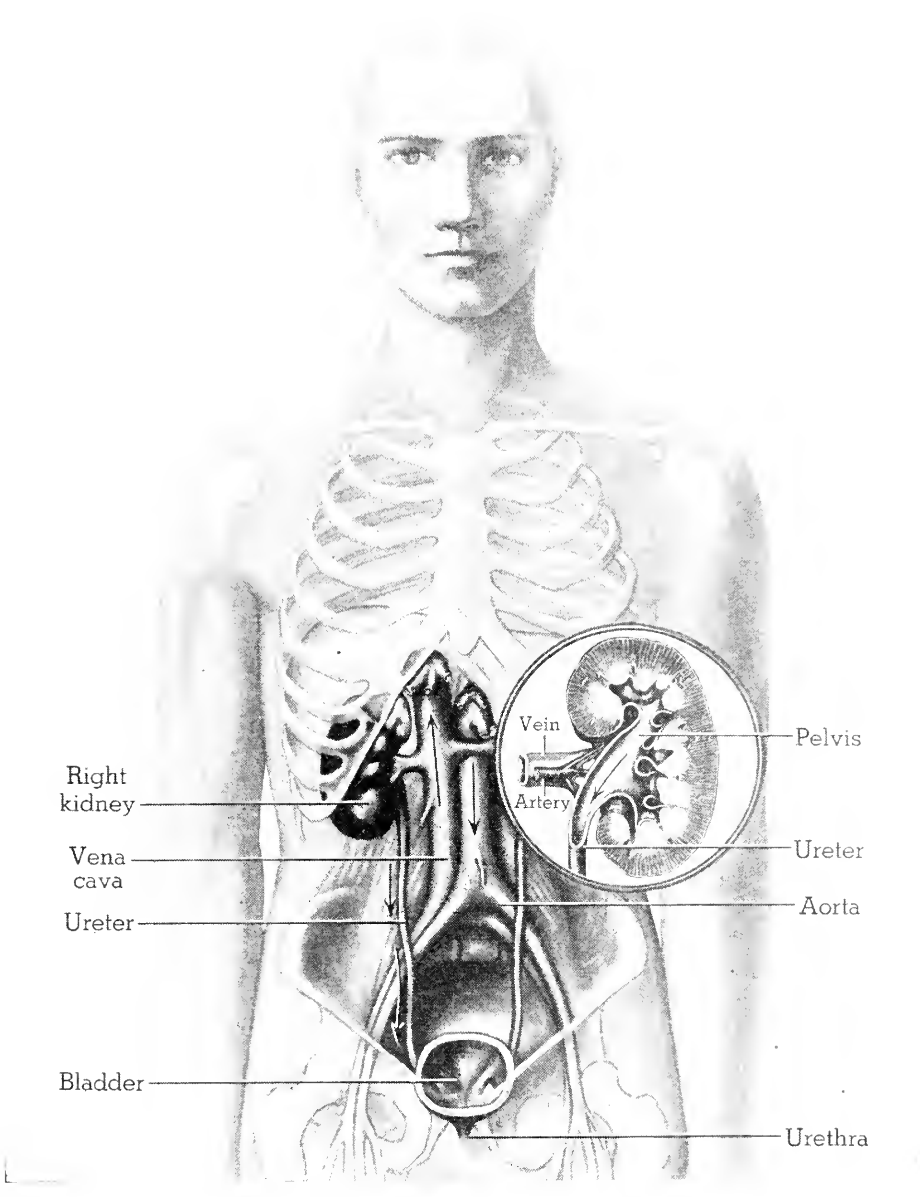
Composition of the Urine[2] The urine is about 96 per cent water. The dissolved substances include inorganic salts and organic substances which result from the breakdown of proteins during metabolism.

Contents of the Urine

INORGANIC SALTS	ORGANIC SUBSTANCES
Sodium chloride	Urea
Sodium, Potassium, Calcium, Magnesium — as sulfates and phosphates	Uric acid
	Creatinin
	Coloring matter

The composition and the concentration of the urine are constantly changing. The proportion of solids and water varies with the activities of

[1]See No. 1, p. 226. [2]See Nos. 2, 3, and 4, p. 226.

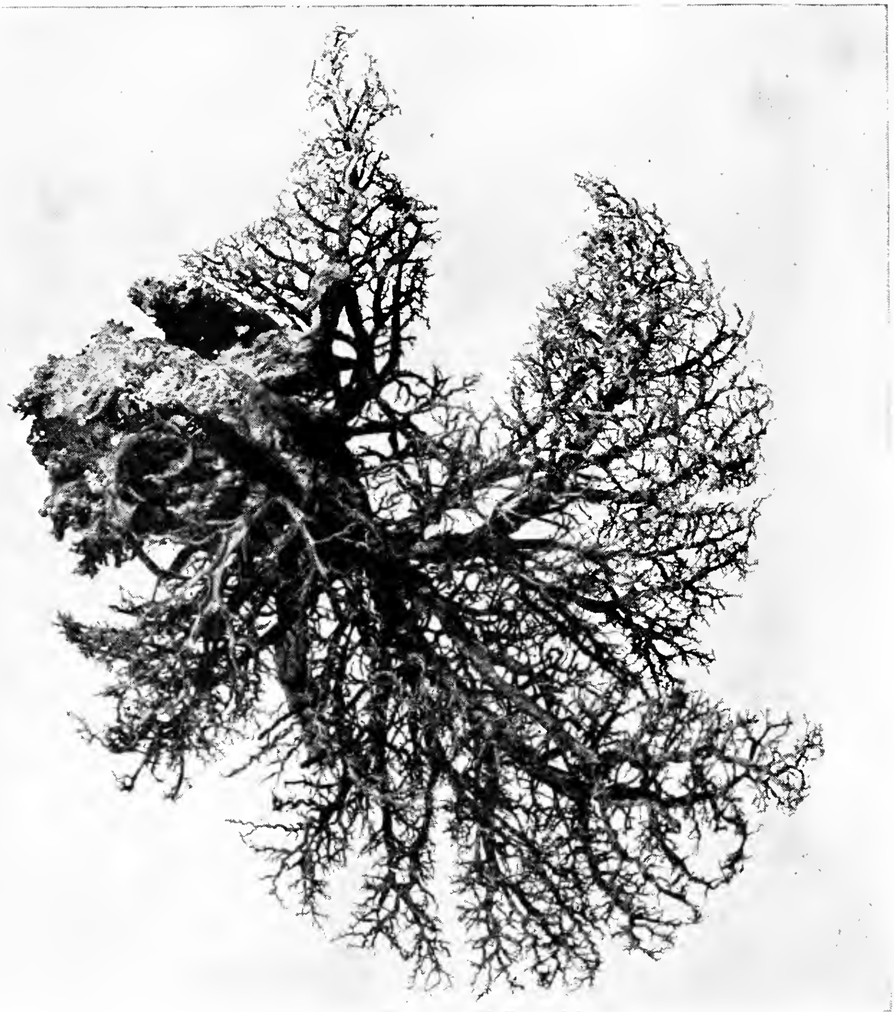


KIDNEYS AND BLADDER

Blood is carried to each kidney by a branch from the descending aorta. The smallest arteries form a network of capillaries within the cortex and the medulla of the kidney. Veins carry blood from the capillaries to the descending vena cava. Urine secreted from the capillaries of the cortex passes through collecting tubules that open into the pelvis. By peristaltic motion urine is forced through the ureter into the bladder, in which it is temporarily stored, being expelled at intervals through the urethra

the organism and with the temperature. Increased sweating, for example, removes water continuously. And unless this is made up by taking in more water, the urine will be more concentrated. On the other hand, any excess of water taken in is quickly removed by the kidneys, so that the urine becomes diluted.

During strenuous exercise albumin may be temporarily present in the



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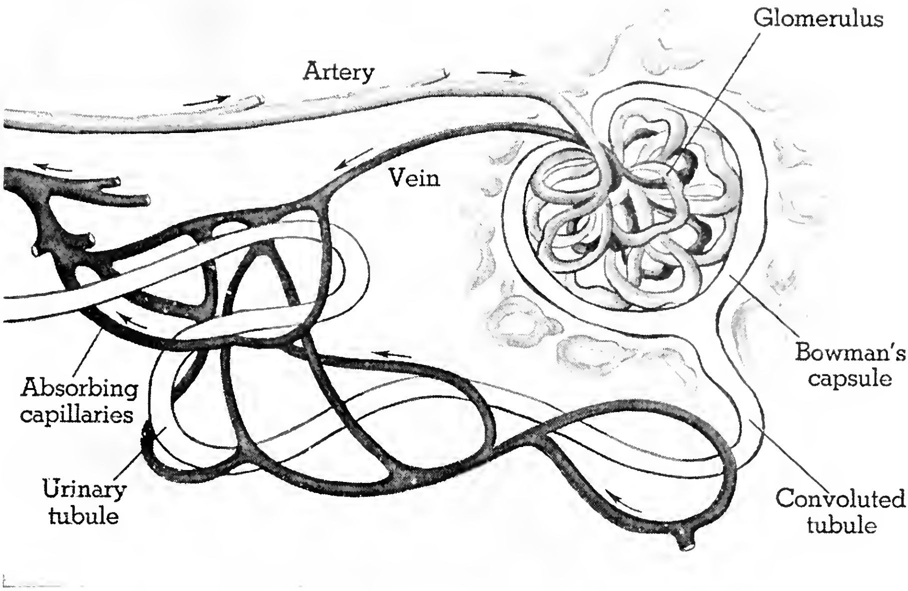
URINE-COLLECTING TUBES IN A KIDNEY

If the urine tubes of a sheep's kidney are filled with latex and all the tissues are then corroded away chemically, there remains a "latex cast" of the tube system. This shows how the urine discharged from the thousands of uriniferous tubules in the cortex of the kidney is collected in the pelvis



THE REMOVAL OF WASTES BY THE KIDNEYS

Each tubule starts from an enlarged double-walled capsule. Blood from the artery flows first through the capillaries of the glomerulus, out of which waste material diffuses by osmosis. These fluids continue through the tubule, which is very long and very much tangled. The blood continuing past the glomerulus runs through a second set of capillaries, which are closely enmeshed with the tubules. At this stage much of the water, sugar, and salts that had diffused into the capsule becomes reabsorbed into the blood

urine. And sometimes growth is so rapid during adolescence that the albumin content rises. But if albumin is constantly present in the urine, it indicates that the kidneys are in a diseased condition.

The sugar content of the urine is temporarily increased by eating large quantities of sugar. Whenever the sugar content of the blood rises above 180 milligrams per cubic centimeter, sugar overflows into the urine. But when sugar continues to overflow from the body through the urine, a diseased condition is indicated. An excess of sugar in the urine is one of the symptoms of diabetes.

Since the activities of the body are not carried on at an even rate, there is sometimes a draft upon reserves—the glycogen in the liver, for example. And sometimes wastes may be produced faster than they are removed by the excretory organs. In extreme cases, failure of excretion may be fatal: an accumulation of uric acid in the blood acts as poison.

Getting Tired[1] When you "chin" yourself on a bar four, five, or six times, until you can do no more, this does not mean that you will never be able to chin yourself again. After resting awhile, perhaps a day or an hour, or perhaps only ten or fifteen minutes, you can chin yourself again as well as at first. What happens in the first place to make you stop? Or what happens during the rest to enable you to do the work again? As soon as work commences, waste substances begin to accumulate in the cells. The wastes are formed faster than they are carried away. The result is a "poisoning" of the protoplasm of the working cells.

When muscles are working slowly, the glucose fuel is oxidized, first into lactic acid, then into water and carbon dioxide. When muscles work very rapidly, as in running, lactic acid formed in the first stages of oxidation accumulates in the cells and is but slowly removed by the blood. Since the lactic acid results from using oxygen faster than it is supplied by the blood and lungs, it is said to represent an "oxygen debt". During rest this "oxygen debt" is quickly repaid by an increased rate of respiration and circulation (see page 193). In the meantime the lactic acid interferes with the operation of the muscles and in effect "poisons" nerves and other tissues. When hard work is sustained for any considerable time, we say that the muscle is *fatigued*. Some of this lactic acid is distributed by the blood to other tissues of the body, and tissues which have not been active become "fatigued".

Fatigue May Be General We have all been taught that "a change of work is the best kind of rest." To a certain extent this is true. When I am reading a difficult book and begin to doze over it, I am not too tired to play a game of tennis or even to read exciting fiction. But past a certain point, fatigue affects the whole body; getting tired from study unfits one for muscular work or play. Thus records made on the ergograph by any person will show great variation, according to the condition of the body. A record made early in the morning will differ from one made at the close of a game of chess (see illustration, p. 224). From these and similar experiments we have learned that exhausting physical work tires the brain and the sense organs. And we have learned that severe mental work tires the whole body.

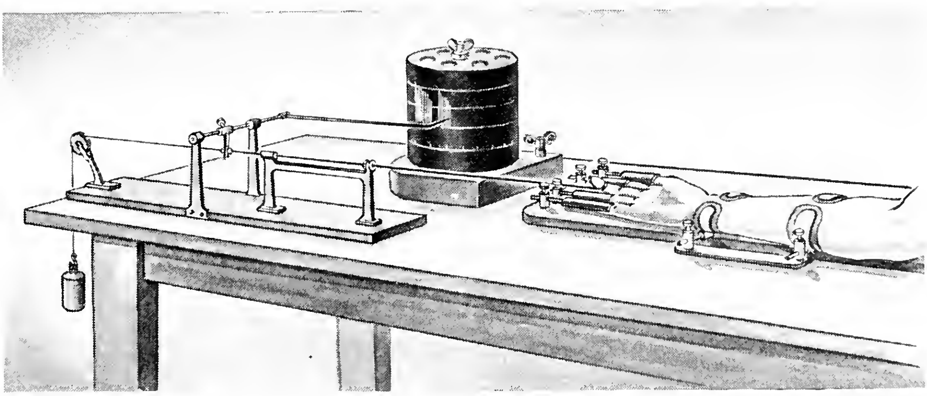
We cannot conclude, however, that hard work is to be avoided. On the contrary, hard work is useful physiologically, as well as otherwise. It stimulates the many metabolic processes and so helps to keep the body in good condition. We can use knowledge about fatigue to organize our work in more effective ways. By planning carefully, by adjusting the rate of work, and by arranging alternate periods of work and relaxation we can do much to reduce fatigue.

[1]See No. 5, p. 226.

Rate of Work When you walk very fast, you may feel tired before you have gone a mile. If you walk slowly enough (but not too slowly), you may walk ten miles without showing signs of fatigue. Getting tired is not altogether a question of what kind of work we are doing, nor of how much. It is partly a matter of how fast we are doing it. "It is the pace that kills" (see illustration, p. 225). Physiologically this means that (1) at a certain rate or speed, lactic acid and perhaps other fatigue substances are formed faster than they can be removed by the blood, and from the blood by the kidneys, etc.; and (2) when work is done at a certain slower speed, the blood can remove the wastes just as fast as they are formed. This principle has its everyday applications in athletics, in play, in housework, in schoolwork, and in industry.

Fatigue and Efficiency In emergencies men and women exert themselves to the point of exhaustion. When we manage our own time and efforts, we sometimes find it expedient to work under great pressure, expecting to even up the organism's account later. In managing other people's work and time, the problem and the motives are essentially different. But studies made by engineers and physiologists have shown that in the long run the greatest output of work is possible only where fatigue is systematically avoided.

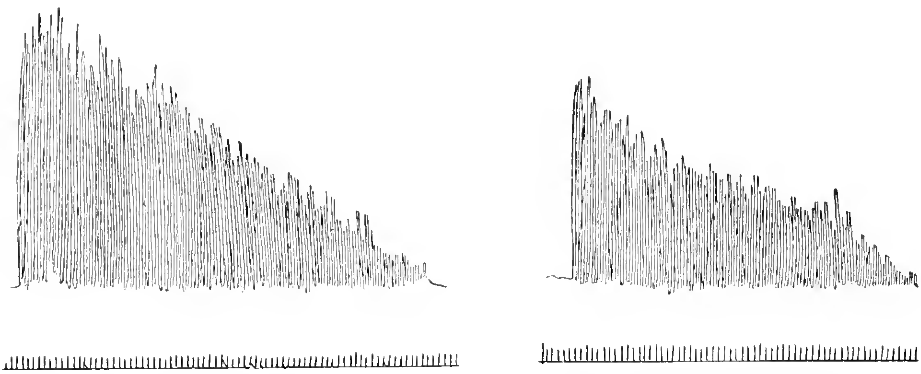
It is difficult to observe the maxim "Make haste slowly" when we are eager to get as much as possible from the work of others. People can endure a spell of exceptional exertion if it seems necessary, but everybody hates to



A MACHINE FOR MEASURING WORK CAPACITY AND FATIGUE

The ergograph measures and records the frequency and the strength of a pull exerted by a finger while the rest of the hand is held firmly in place. In the record, the heights of the vertical lines indicate the relative amount of energy output for each pull on the ring. The distances between vertical lines correspond to the time intervals between pulls

be driven. Workers may resent the "speedup" because they fear being overworked, but they probably resent even more having the pace set for them



MORNING RECORD

LATE–AFTERNOON RECORD

These two records on the ergograph were made by a medical student on the same day. Although he made no special exertions with his middle finger during the day's work, the record made by the pulls of this finger show a general fatigue—that is, one of the whole body—toward the end of the day

by somebody who is unconcerned about their continued well-being. In trying to make the most out of mass-production methods we have generally overlooked the fact that individuals differ with regard to their working rhythms and resistance to fatigue. When a machine sets the pace for a large block of workers, some of the individuals are almost certain to be overworked, while about the same number will be kept from working at their own best speed.

The First World War compelled works managers to select workers more carefully for the various tasks. The Second World War forced them to go even farther: they must determine "average" speeds and hours of work in relation to the capacities and limitations of the particular organisms under their direction.

Early in the Second World War, British factories quickly intensified their efforts to increase the production of war essentials by speeding the work and also by increasing the hours of work. In a short time it was found that accidents increased, workers collapsed, and the actual output failed to keep up with plans. In this country workers in many plants were tempted to work extra long hours to earn the additional wages. But within a few months after the United States was at war it was found necessary to restrict the number of hours a worker might keep at his job to forty-eight a week. These regulations were based on studies of the effects upon workers of

staying too long at the job without suitable rest periods. The regulations required also a full day of rest in seven, and vacation periods as well as adequate time allowances for lunch. Excessive work schedules were found to reduce the flow of production as well as to impair the health and efficiency of the workers.

In Brief

Among the substances produced in living things during metabolism, some are useless or even injurious to the protoplasm.

Plants eliminate carbon dioxide and water, but usually accumulate other wastes in insoluble combinations in various tissues, where they do not interfere with vital activities. Animals deposit wastes in special tissues of the body to a slight extent.

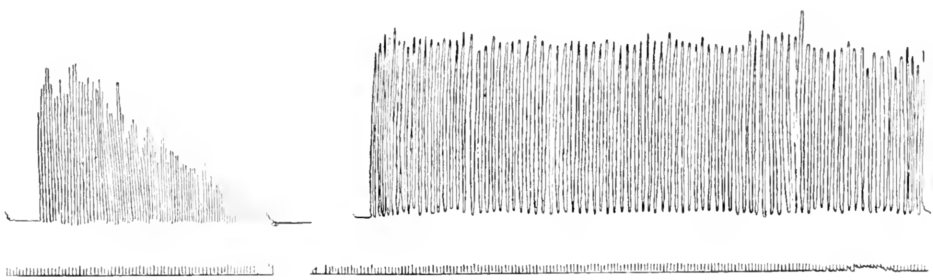
In the higher animals wastes are diffused into the blood and removed from the body by special organs, such as sweat glands and kidneys, or by the intestines.

In the vertebrates, nitrogenous and other wastes are removed from the blood by the two bean-shaped kidneys.

Each kidney consists of a mass of tiny tubules interwoven with a complex network of capillaries. The wastes diffuse from the blood into the tubules, from which they are discharged from the body as urine.

The urine, which is about 96 per cent water, contains dissolved substances resulting from the breakdown of proteins during metabolism.

The composition and concentration of the urine are constantly changing.



THE PACE THAT TIRES

These two ergograph records were made by the same student. The first he made by pulling as rapidly as he could and as far as he could: this shows fatigue coming on rapidly. The second was made by a slow, steady pull, taking two seconds each time. Although the action continued twice as long in the second case and the actual work performed was about four times as much, there is hardly any evidence of fatigue

The continued presence of albumin or of sugar in the urine indicates a diseased condition of the body.

When wastes accumulate in active tissues faster than they can be excreted, they are diffused to other tissues and may bring about a state of general fatigue.

An excess of uric acid in the blood may be fatal.

Efficiency in work can be increased by setting a pace that will avoid fatigue through balancing metabolism and excretion.

EXPLORATIONS AND PROJECTS

1 To study the position and structure of vertebrate excretory organs:

Dissect an anesthetized frog, guinea-pig, or rat, opening it on the undersurface, and remove the viscera. On either side of the backbone will be found the two bean-shaped kidneys. The ureters, the bladder, and the urethra may be seen in their normal position. The arteries and veins leading to and from the kidneys may also be readily seen.

Cut a sheep or beef kidney lengthwise through the "pelvis". Note general structure.

2 To find the specific gravity of a sample of urine, float a hydrometer in the urine placed in a tall cylinder. (Clear amber-colored fluid normally has a specific gravity of about 1.02.)

3 To determine whether urine is acid or alkaline, use litmus paper or phenolphthalein or nitrazine paper. The reaction is usually slightly acid because of the presence of acid sodium phosphate (NaH_2PO_4).

4 To test urine for sugar, use Fehling solution (see footnote 1 on page 183).

5 To observe the effect of fatigue on muscular activity, note the change in rate and speed of work as several individuals "chin" themselves as many times as they can without stopping.

QUESTIONS

1 How do waste products originate in an organism?

2 What waste products of metabolism are harmless to protoplasm? What products are injurious?

3 How are the waste substances of plants separated from the living parts of the organism? How do animal cells dispose of wastes?

4 In the higher animals, how is the waste removed from the many cells throughout the body?

5 In the higher animals, what specialized organs remove the wastes of metabolism from the body?

6 How is the structure of the kidney related to its function?

7 What factors affect the composition and the concentration of the urine?

8 What is indicated by the continued presence of glucose in the urine?

9 What is indicated by the continued presence of albumin in the urine?

10 What is the advantage of a vigorous sweat? the disadvantage?

11 What are the advantages of cold baths? the disadvantages?

12 Why is it important to prevent the accumulation of refuse in the large intestine for a long period?

13 What are the advantages of standardized working hours? the disadvantages?

1. How can a sick person get well?
2. What makes an organism sick?
3. Are all kinds of diseases caused by bacteria?
4. Are blood sicknesses inherited?
5. Does vaccinating prevent all diseases?
6. What is antitoxin?
7. Are there antitoxins for all diseases?
8. Can any medicine be suitable for all kinds of sickness?
9. How does one become immune to certain diseases?
10. What is the difference between a serum and a vaccine?

Living things are always exposed to mechanical injuries. A fish snaps at another fish and gets away with only part of the prey. A wind blows a bough off a tree or tears off a piece of bark. A bird catches a lizard by the leg, and the lizard slinks off on his remaining three. A parasite gets inside an animal and destroys part of the tissues, or it excretes substances that are poisonous to the host. Such dangers are parts of the risks of living.

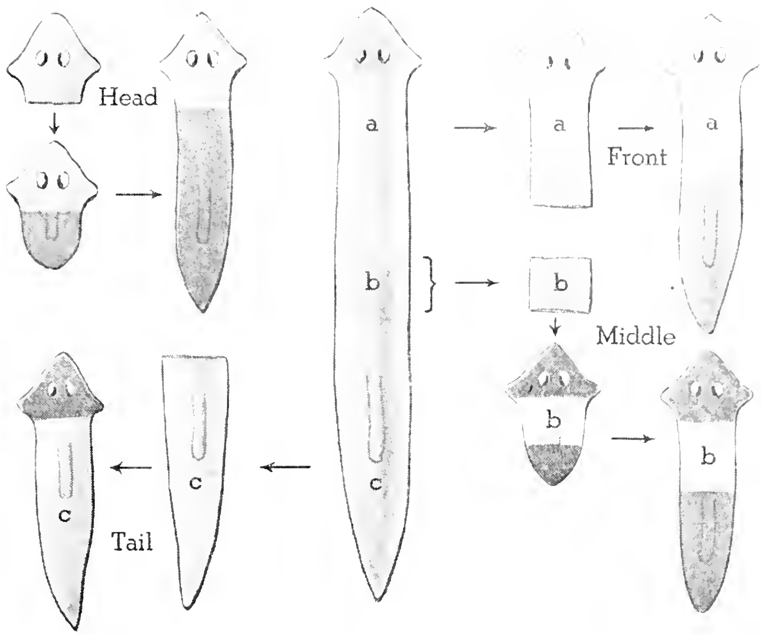
If an injury is too extensive, or if too much of an organism is removed or destroyed, death is likely to result. But how much is too much? What happens when the injuries are chemical, or result from poison? How does a sick organism recover? How much punishment can an organism take and still continue to live?

How Much Damage Can an Organism Endure?

Healing and Regeneration[1] Plants and animals of nearly all classes repair mechanical injury by growing new tissue that closes the wound. In organisms like ourselves the gap in the tissues at first fills with fluid from the surrounding cells and spaces—lymph. Then the surrounding cells multiply rapidly, forming new cells. (This rapid formation of new cells is called *proliferation.*) Such healing is almost universal. But it is not equally effective among all species, nor among all the tissues of a given plant or animal.

At one extreme, planarians will *regenerate*, or regrow, complete individuals from rather small fractions of worms (see illustration opposite). The earthworm can regrow the missing part if its hind end is cut off. Oystermen who formerly tried to slaughter the destructive starfish by chopping them with hoes and shovels discovered that the enemy could regenerate the parts

[1]See No. 1, p. 246.



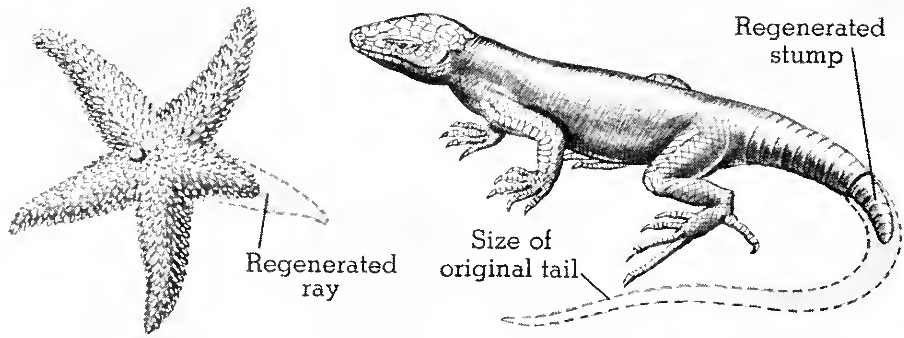
REGENERATION IN FLATWORMS

Experiments with flatworms show the regeneration of a complete animal from a segment. If the head is removed, if the hind part is removed, if a section is cut from the middle, a complete animal will be regrown. The shaded areas represent the new growth

removed. A lobster will regrow a complete new claw. Salamanders regenerate complete tails and legs. The glass snake (which is really a lizard with reduced legs) leaves his tail behind when it is grasped, but then grows himself another (see illustration, p. 230).

At the other extreme are more highly specialized warm-blooded organisms. We can regrow skin, or bone, or connective tissue. When nerve and brain cells are injured, however, they are replaced by scar tissue. Scar tissue closes a gap, but it does not have the characteristic of nerves, nor does it do the work of the destroyed nerve cells.

Plants usually heal wounds more directly: exposed cells dry up. In many cases, however, regeneration or healing may be observed. In some species, even a small piece of leaf or stem may regenerate leaves and roots and, under suitable conditions, a complete plant (see illustration, p. 231). When the bark is scraped from a tree, and the growing layer is exposed, proliferation of cells results in a mass of *callus*. This covers the wound but does not continue to grow.



REGENERATION IN STARFISH AND LIZARD

A starfish can regrow as many as four rays to full size, if the disk remains intact. Many lizards will regrow missing limbs or tails. In the regenerated tail of Ameiva from Dutch Guiana there are no vertebrae

Growth Substances Biologists have long been puzzled by the various ways in which plants and animals respond to injury. Healing and regeneration are obviously adaptive: they help to preserve the injured or mutilated individual. But what makes the healing start? One suggestion is that the tissues stopped growing in the first place through the action of the cells upon one another. That is, each cell might still be able to grow and divide but is kept from doing so by the presence of neighboring cells. When cells are broken, however, two conditions are changed: (1) there is now more room for further growth, and (2) injured cells may throw some growth substance into the surrounding space.

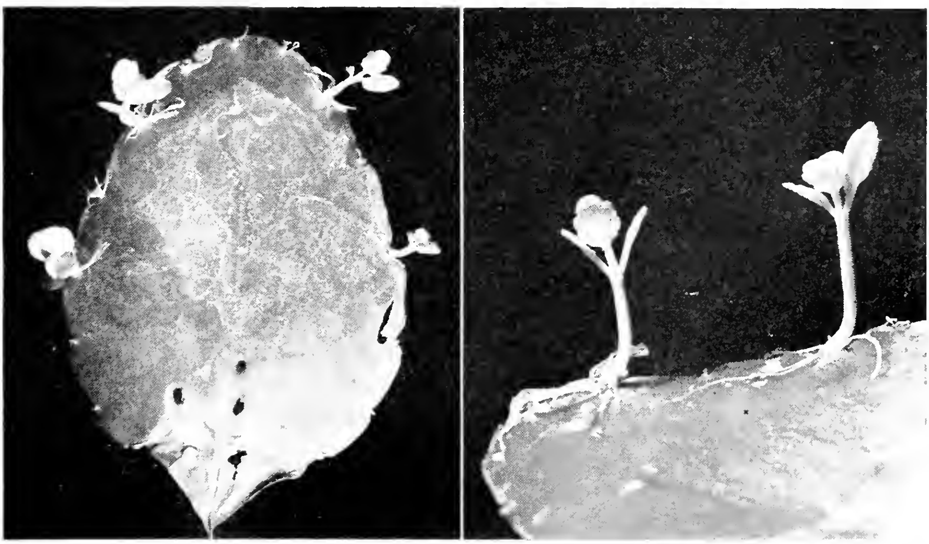
These new conditions might explain the sudden proliferation of new cells into the space formed by a wound. According to experiments by George Sperti (1900–   ) and associates at Cincinnati and by other investigators, injured cells do produce substances that stimulate cell-division of living cells. From yeast cells and chicken embryo cells killed under suitable conditions, experimenters removed special substances that hasten the growth of injured tissues. Ointments prepared from such materials have been very helpful in healing severe burns and other wounds. Incidentally, these studies have furnished some clues to the further investigation of the causes of cancers. Cancers are "wild" growths in tissues that had already completed their normal development: the idea is that injured cells introduce special growth substances and so bring about abnormal proliferation.

Poisons The idea of poisoning must be very old in the experience of the race. Something taken into the system interferes with comfort or with life. Acids and alkalies obviously injure tissues, as on the skin. Undoubtedly

they act in similar ways when taken into the system. Poisoning may be of various kinds. Thus certain substances combine with proteins in ways that interfere with normal metabolism. Some substances retard, others accelerate, metabolism. Some substances seem to attach themselves to special tissues.

Among inorganic poisons the most dangerous for human beings are compounds of lead, mercury and phosphorus, which are used in certain industries. Since about 1910 legislation has stopped the use of white phosphorus in the manufacture of matches because the fumes caused serious injuries in the workers. More recently, radium compounds, used for luminous watch and instrument dials, were found to disturb seriously the metabolism of those who work with such materials; and strict regulations have been adopted to prevent further injury.

Some of the most useful drugs obtained from plants are poisons of the alkaloid group, such as morphin, atropin and quinin. These act in specific ways, but often produce undesirable results along with their useful results; and they are dangerous in large doses. For these reasons scientists have been trying to find substitutes that are more readily controlled, in the form of artificial synthetic compounds. The specific substances are not all useful, nor do they act equally on all living things. Hens, for example, appear to



Hugh Spencer

REGENERATION IN LEAF OF BRYOPHYLLUM

The leaves of bryophyllum, of begonia, and of a few other genera will form complete plants if removed from the stem. In some experiments with bryophyllum leaves, a plant was regenerated at each notch when the leaf had been cut into strips from the edge to the midrib

be indifferent to the action of morphin, and rabbits are insensitive to the alkaloid atropin, or belladonna.

Members of the same species also differ greatly among one another. Some persons are more susceptible than others to the effects of tobacco or alcohol; some more susceptible to the specific poisons of particular kinds of bacteria. How various poisons act upon the organism and how they can be counteracted are the problems of a special study—*toxicology*. In the last few decades we have learned a great deal about how the body reacts to foreign substances of various kinds.

How Is Protoplasm Influenced by Foreign Substances?

Getting Used to Changed Conditions There are many kinds of fish that live in salt water only, and there are many kinds that live in fresh water only. Some species, however, such as the salmon and eel, spend part of their lives in the ocean and part in fresh water. Still, if we took one such fish out of the ocean and placed it in fresh water, it would soon die. Or if we took one from fresh water and put it into salt water, it would soon die. But if we slowly dilute sea water, or gradually concentrate the salt in fresh water, we can keep some fish alive now in one medium and now in the other.

In a case of this kind we say that the animal "gets used" to living in the new conditions. This illustrates a pretty general fact about protoplasm, or about living things. Living things can get used to new conditions of temperature or of light or of chemicals or of food. This does not mean that *every* living thing can come to live in *any* kind of surroundings whatever. That is not true. Birds cannot get used to living in water; fish cannot get used to living in the air. Plants and animals cannot get used to living without proteins or without salts. But we can all change our conditions of living to a certain degree or in certain directions and still remain alive.

Habit-Forming Poisons Arsenic is poison to all kinds of protoplasm. It is used in fighting many kinds of insects and many kinds of fungi. A very small amount of it will kill a person or a rabbit.[1] In experiments this substance was fed to rabbits in very small quantities—a fraction of the quantity enough to kill. After a few days the animals were given a little more. The dose was gradually increased until the animals could stand several times the ordinary fatal dose. The arsenic acts upon the protoplasm of the nerves or muscles to put the animal in a state of tonus, or stretch—that is, the way one feels when one is "all on edge", all set to jump or scream on the least provocation. The treated rabbits thus became extremely sensitive to the slightest disturbance. They would jump on hearing the faintest sound,

[1]Strangely enough, a child can tolerate more arsenic than an adult.

or on seeing the slightest movement or the passing of a shadow. But still more curious, after the animals had been fed the poison in this way for a considerable time, they became unable to live without it. If the drug was omitted from their daily rations, they quickly died.

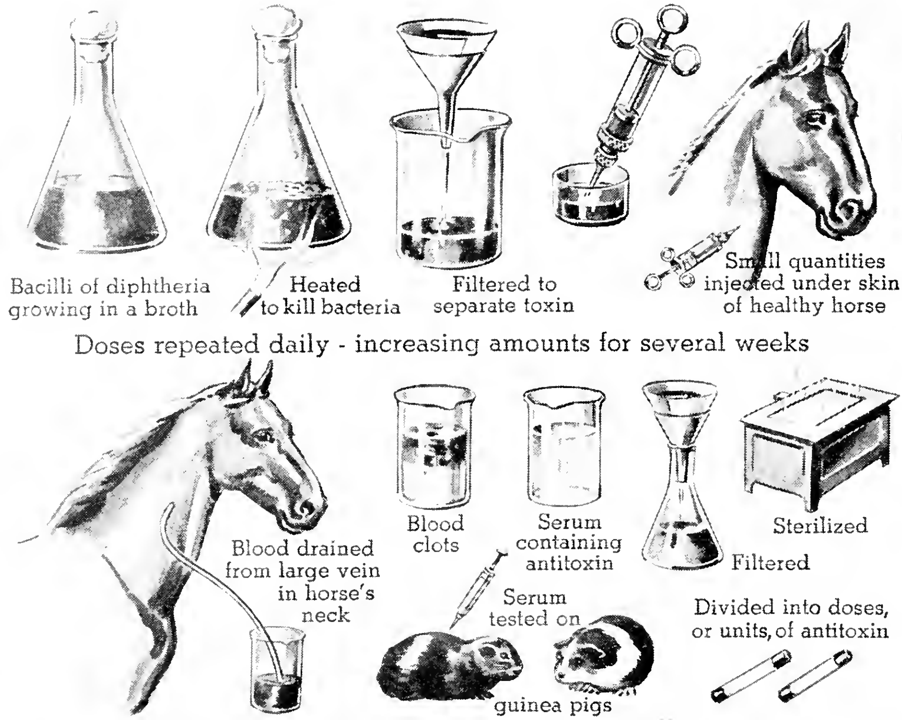
The rabbit's protoplasm adjusted itself to new surroundings. The protoplasm became able to live under conditions that would normally destroy it. In experiments with bacteria similar results were obtained. Bacteria of various species were placed in dishes with the usual food materials, but with the addition of a small amount of phenol or other germicide. When the colony had about used up all the food in the dish, some bacteria were transferred to a similar dish containing a slightly greater concentration of the poison. This was repeated several times. In the end there was a growth of bacteria that could tolerate much more poison than would normally kill their ancestors.

Persons suffering from malaria are systematically treated with quinin to keep the parasite in check. After a long and seemingly successful treatment a patient sometimes relapses. It has been suggested that in such cases the malaria parasite has become able to tolerate relatively large quantities of quinin, so that it is useless to drug the patient further.

Such observations suggest that while each particular kind of protoplasm thrives best in a particular set of conditions, it is able also to adjust itself to different conditions—provided they are not too different. It is not clear just what change takes place in the protoplasm itself under such circumstances.

Antitoxin Different kinds of bacteria produce substances that act as poisons in the bodies of animals. Such protein poisons, or toxins, are found also in the venom of various snakes and in the tissues of various higher plants. When some toxin gets into living tissue, it stimulates the protoplasm to produce specific neutralizing, or counteracting, substances. The reaction of the invaded protoplasm may be compared to some of the chemical processes that bring about homeostasis—the release of acid under the stimulus of alkali, and vice versa (see page 193). The reaction of protoplasm to the toxins is apparently much more complex, however. The counteracting substance produced by living cells under the influence of a toxin is called an *antitoxin*, and it is always specific. That is, it will neutralize the poison under whose stimulation it was produced, but no other.

Among the best-known toxins are those produced by the bacteria that cause lockjaw and diphtheria. When a quantity of toxin, not enough to kill, is injected into the blood of a healthy animal (a young horse, for example), the cells begin to produce and excrete antitoxin. They will produce more than enough antitoxin to neutralize the poison received by the body, and the surplus antitoxin remains in the blood. This surplus can then



PREPARING DIPHTHERIA ANTITOXIN

For making antitoxins, carefully selected and perfectly healthy young animals are used. The toxin is produced by millions of bacteria grown in special nutritive solutions. The dissolved poison is filtered from other substances in the culture, which is heated to kill the bacteria. Increasing doses of toxin are injected into the animal over two to three months. Blood is drawn from the animal from time to time; after the blood clots, the antitoxin is in the serum. After the removal of other materials the serum is tested both for its potency and for the possibility of any injurious substance being in it. It is then put up in sealed units for use against diphtheria

be used to cure a person infected with the corresponding disease germs. That is, the antitoxin produced in the body of a horse or a goat is used to reinforce the natural capacity of the human body to combat the poison of the invading germs (see illustration above).

Are Chemical Changes in an Organism Permanent?

Modified Protoplasm If the body recovers from a mechanical injury, it may afterward be exactly as it was before, for all we can tell—except perhaps for some mutilation. But when a person recovers from certain kinds of sickness, there are apparently lasting changes in the protoplasm. It

is a common saying that "you can't have measles twice". The changes which make one immune during mumps, whooping cough, scarlet fever, yellow fever and diphtheria are practically permanent.

In former times, people in Asia and in southeastern Europe took advantage of the fact that recovering from smallpox usually meant a degree of immunity. They would induce the disease in a mild form by inoculating a person with pus from a patient having the disease. After recovering from the induced smallpox one was just as immune as if he had "caught" it unintentionally. Instead of taking a chance with an epidemic, one could choose to have the disease in a comparatively mild form and perhaps at a convenient time.

The practice of inoculating against smallpox had long been common in the East. It was not brought to the attention of western Europe and England until about 1720, through Lady Mary Wortley Montagu, the wife of the British ambassador to Turkey. Inoculation was shown to be relatively safe, as well as effective. Many physicians began to inoculate against smallpox, but the practice met with a great deal of opposition. It was sometimes unsuccessful. Worse still, it sometimes resulted in introducing another disease. In some cases an inoculated person infected somebody else, who then suffered a violent or fatal form of the disease. Inoculation was, at any rate, a strange practice, contrary to familiar customs and to "common sense". George Washington wanted all his soldiers inoculated; later, laws were passed forbidding inoculation.

For nearly a hundred years controversy raged about inoculation in England, in this country, and in all parts of Europe. Then an English physician, Edward Jenner (1749–1823), was told by a dairymaid that there was no use inoculating her, for she could not have smallpox—she had once had "cowpox". To a learned physician, this was merely ignorant folklore. But to a scientific physician, it was something to look into. Jenner found that this idea was quite general among dairymen and dairywomen, and that they could cite any number of cases. Moreover, dairy people actually had less than their proportion of smallpox. Since cowpox is a very mild disease, Jenner saw advantages in using *cowpox* pus for inoculating—*if* it would work. He tried it. He inoculated a boy with *cowpox*. After several weeks he inoculated the same boy with *smallpox*. This did not "take". He tried it again, with the same negative results. Later he tried the experiment on others. He concluded that *a cowpox inoculation protects against a smallpox inoculation.* Would it also protect against smallpox "caught" in the usual way?

Vaccination[1] After years of experimenting, Jenner came to the conclusion that the cause of cowpox is related to the cause of smallpox. He

[1]See No. 2, p. 246.

© National Portrait Gallery

EDWARD JENNER (1749–1823)

Jenner had received irregular but good training in pharmacy and surgery, having studied under the great John Hunter; but he preferred to practice medicine in his small home town. Hearing of the common belief that those who had recovered from the "cowpox"—a mild disease common among dairy workers—could not take smallpox, he watched for a chance to test this experimentally. From his work the practice of vaccination rid the world, in time, of smallpox, except in a few out-of-the-way places

called this mild disease *Variola vaccinae* (that is, cow-variola; *vaccinae* is from the Latin *vacca*, "cow"). Today the term *vaccination* is used loosely for any procedure that brings about immunity, whether or not the active "germ" or *virus* is introduced. The general principle involved is that foreign material stimulates the organism to produce something that counteracts *it*. That is, as a result of the treatment, the body *actively* produces the *anti*bodies. This is in contrast to inducing *passive* immunity by adding antitoxin to the blood, as in a case of diphtheria.

In typhoid-fever "vaccination", cultures of the bacteria are killed and then introduced under the skin. Active immunity against diphtheria is brought about by means of a mixture of the toxin with some antitoxin. The antitoxin protects the body against the poison, but the free toxin stimulates

the protoplasm to form more antitoxin. In using toxoid, lasting immunity is brought about usually with one or two injections.

Permanent Values of Immunization There is no evidence that immunity acquired in a person's lifetime is transmitted to offspring. However, a baby may be for a time immune as a result of substances developed in the mother's blood during pregnancy. Artificial immunization may not last a lifetime. Vaccinating or immunizing is nevertheless of tremendous value for those communities that have learned to use it.

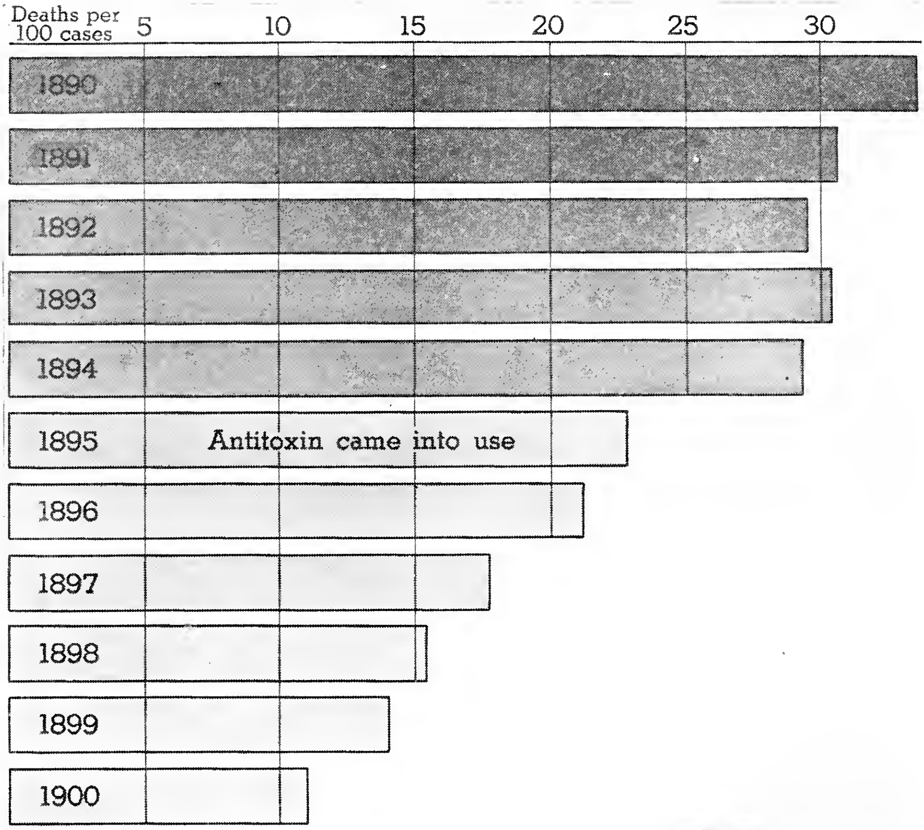
Before the German bacteriologist Emil von Behring (1854–1917) worked out the antitoxin principle in the early nineties, diphtheria was most dreaded by parents. For this disease in children was not only very distressing, but resulted in a very high proportion of deaths—45 per cent or more. The widespread use of antitoxin as a cure has so reduced the fatality from diphtheria that it is no longer dreaded as a scourge. However, it was the systematic immunization of children to *prevent* the disease that reduced the prevalence of diphtheria. There are now many cities that have for years been free of diphtheria.

Antitoxic serums have been developed against the poisons of gas gangrene, the tetanus or lockjaw organism, and botulism. In none of these cases has the antitoxin resulted in such striking success as in that of diphtheria. This is largely because some toxins destroy living protoplasm before the

Compulsory vaccination	Local option	Do as you like
13 states (including the District of Columbia) Population: 43,000,000	14 states Population: 41,000,000	22 states Population: 49,000,000
Number of smallpox cases in the eight-year period		
2,462	11,551	52,680
Average number of cases per year		
308	1,444	6,575
Average number of cases annually per million inhabitants		
7.1	35.2	134.2

SMALLPOX AND VACCINATION IN THE UNITED STATES (1933–1940)

In three groups of states divided according to their vaccination laws, average annual smallpox cases per million inhabitants varied from 7.1 to 134.2. In at least eight of the states in the "Liberty" group conditions were worse in recent years than they were twenty years earlier. And in recent years the United States had more cases of smallpox than any other country except India



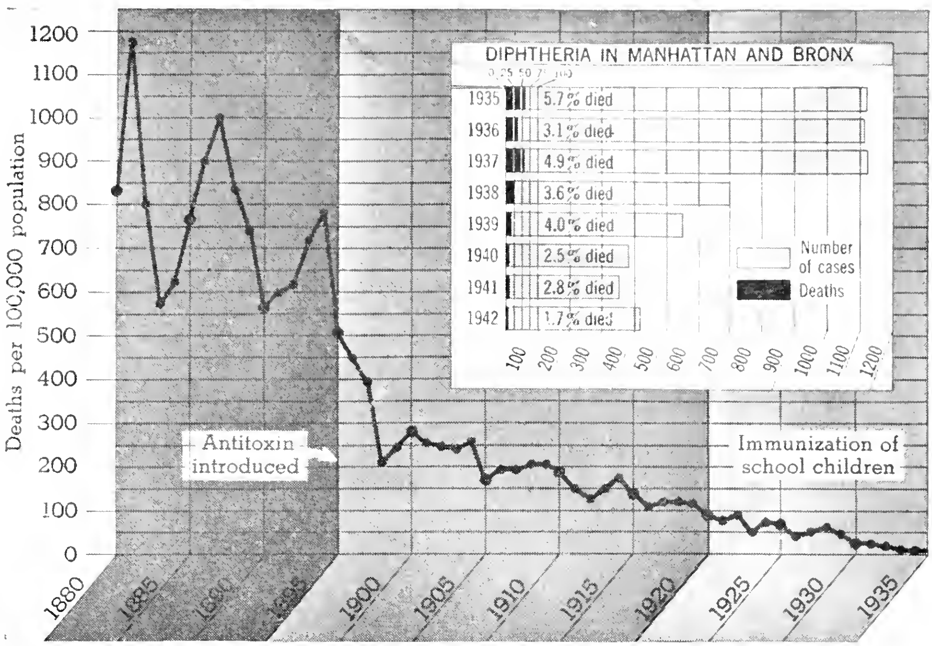
HOW ANTITOXIN SAVED LIVES

The records of a large metropolitan hospital in London showed the number of deaths in each hundred cases of diphtheria for five years before and five years after antitoxin came into use

presence of the disease can be recognized. The antitoxin is then without effect. Tetanus antitoxin is a dependable preventive, but the disease is too rare to warrant routine inoculations. Doctors use it wherever a wound may have become infected with the tetanus organism.

What Kinds of Anti Bodies Do Organisms Produce?

Protoplasm Strikes Back We cannot measure humanity's gains from Jenner's work in preventing smallpox, or from Behring's work a century later in curing diphtheria. We can say that two very important sources of mankind's miseries have been wiped out completely in many regions, and are being pushed farther back as fast as people make use of our knowledge.



DECLINE OF DIPHTHERIA AS A CAUSE OF DEATH (1880–1942)

The long zigzag line shows the fluctuation in deaths from diphtheria per 100,000 population in New York (Manhattan and Bronx, for which the most complete records are available). After 1895, when antitoxin came into use, there is a rapid drop, and then a steady decline for twenty-five years. With the introduction of the Schick test for susceptibility and the immunization of children against diphtheria, this disease became an almost negligible cause of death. The record for the last few years is shown in the inset, as the figures are too small to show on the large graph

And we can say that the lives of millions and millions of children have been prolonged into adulthood. But these two discoveries illustrate an important principle of living matter. They lead on to a better understanding of life, and possibly to better ways of managing our lives.

The important principle in immunization is represented by the familiar fact that if you annoy a cat she is likely to strike back. We might generalize the idea further: *Living matter tends to react to changes in a way that neutralizes or counteracts disturbances in metabolism.* Chemical disturbances call out chemical responses. A specific poison calls out a specific counter-poison—something that is chemically related to *just that*, and not to disturbances in general, not to poisons in general.

Chemical Conflict We may think of the formation of an antitoxin as a normal result of the interaction between two kinds of protoplasm. It should not seem strange that among the hundreds of species of micro-

Shortly after the bacillus which causes diphtheria was discovered by Friedrich Loeffler, in 1884, Emil Behring hit upon the idea that a living organism "fights back" against the attacking parasite by some chemical means. In the meantime Émile Roux, a French investigator at the Pasteur Institute in Paris, found that the bacilli of diphtheria produce a virulent poison. After long and difficult experimenting, Behring established the principle of "anti-toxin". He produced a sheep serum with which he cured guinea pigs and rabbits that were sick with diphtheria. Roux started to make gallons of antitoxin serum by using horses. In 1901 Roux and Behring together received the Nobel prize for their important contribution

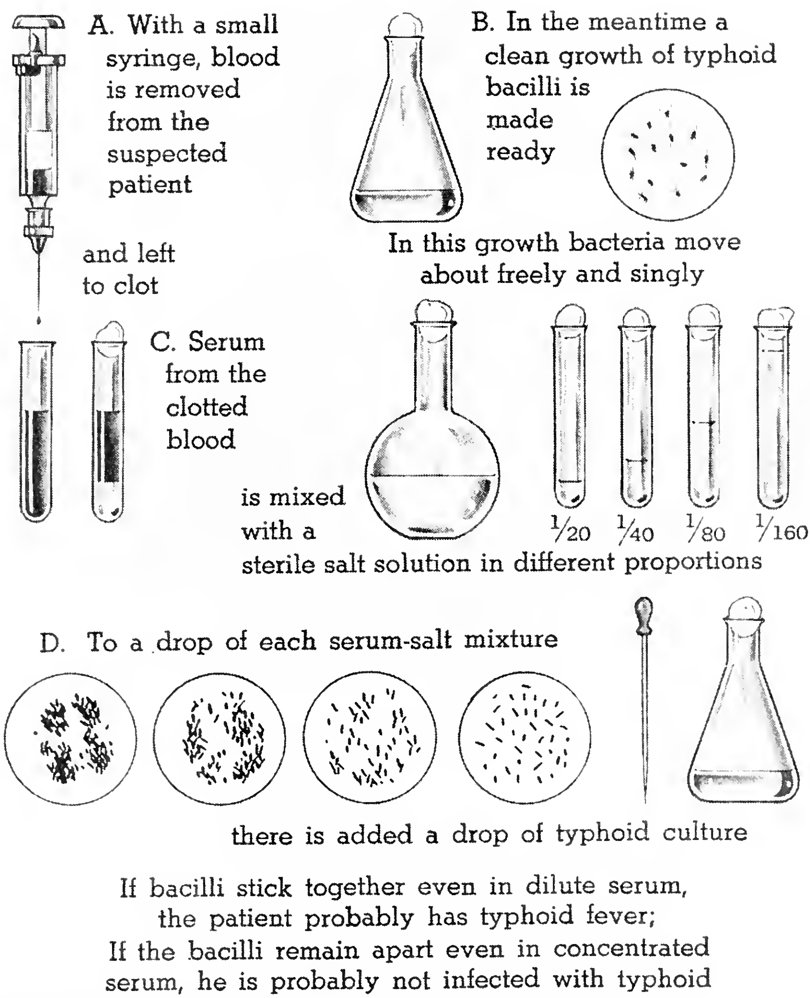
EMIL VON BEHRING (1854–1917)

organisms living in the soil, a particular species will produce a substance that is injurious to some other species. This seems, indeed, to be a general fact, although few particular cases have been worked out. Some species of *Penicillium*, the very common "blue" or "green" mold (see illustration, p. 375), produce a substance that is destructive of certain species of bacteria. This substance, *penicillin*, has been extracted and found to be a very powerful germicide, or germ-killer. It has been found so helpful during the Second World War that many special plants have been established for producing it on a large scale. Investigators are experimenting with the idea of growing the mold *Penicillium* on wound dressings and so preventing infection.

The experiments so far made suggest an explanation for the fact that when infected materials are buried in the earth, they appear in time to become "purified". By means of experiments biologists and other scientists have found that organisms react to injurious foreign substances in many different ways. We may consider the formation of antibodies in larger organisms as adaptive changes in the blood. But since we cannot detect these changes with a microscope, or even by ordinary chemical means, we look for them in the behavior of the serum—the clear fluid left after the clot is removed from blood.

Blood-Serum Reactions When white-of-egg is placed in the stomach of a backboned animal, it acts as food. If it is injected directly in the blood (of a rabbit, for example), it produces a totally different effect. If, after several such injections, we mix a few drops of serum from a treated rabbit with water containing some egg albumen, a white precipitate will imme-

diately appear. There has been formed a new substance that does not occur in normal blood serum. This new precipitating substance, or *precipitin*, will precipitate only white-of-egg. If a different kind of protein is used, the precipitin formed will act on *that* only. That is, the precipitin is *specific*. We do not know how the protoplasm of an animal produces precipitin, but we can use what we do know about precipitins in several ways: (1) We can tell whether a bloodstain was produced by human blood, let us say, or by the blood of some other species. (2) We can tell, by the precipitin test, what kinds of meat there are in a sausage or hash, when all other tests fail.



WIDAL'S AGGLUTINATION TEST FOR TYPHOID

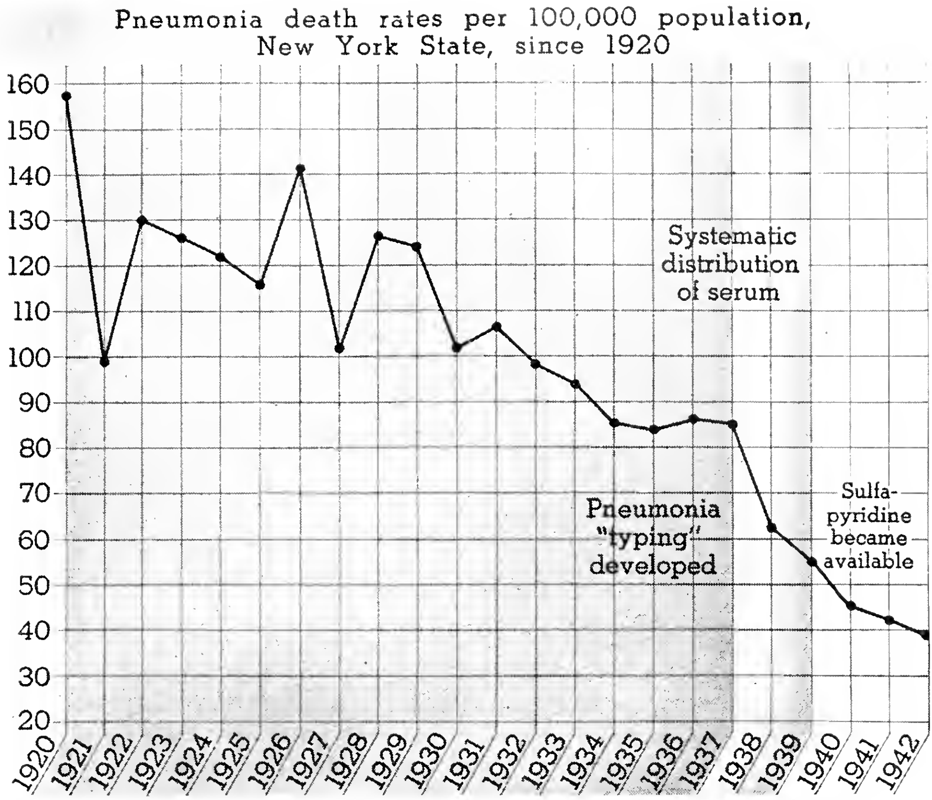
Another type of chemical response to foreign substances is revealed by the serum of a typhoid-fever patient (see illustration, p. 241). The new substance is called an *agglutinin* because it clumps the bacteria together in masses. Like precipitins and antitoxins, agglutinins are specific; that is, each acts only on a particular species of bacteria. The agglutinins do not kill the bacteria, but probably interfere in some way with their action. It is certain that in their presence the phagocytes more readily attack the bacteria (see page 188).

In the blood of a backboned animal, red and white corpuscles float about unaffected by one another. But if blood from a different species is injected into the veins of a rabbit or mouse, say, the foreign red corpuscles are presently destroyed. After the foreign cells are introduced, the body seems to form a new substance that dissolves the invading material. Such specific *cytolysins*, or "cell-dissolvers", are formed in response to various kinds of cells or tissues and to various bacteria. Thus the serum of a rabbit that has been treated with human blood will dissolve human corpuscles, but not those of a goat or a monkey.

Specific Tests of Disease[1] The antibodies that develop after an infection or after an inoculation are specific and are present in the blood. They therefore appear in the serum. We sometimes speak of such a serum as an "immune" or as a "specific" serum. Because of the specific characteristics of such altered serums, we can use them for the quick and reliable diagnosis of certain diseases, as the Wassermann test for syphilis and the Widal test for typhoid fever (see illustration, p. 241). Other tests tell us whether a person is susceptible to a given disease or sensitive to a particular substance. The Schick test is used to show whether a person is immune or susceptible to diphtheria. Similar tests are used to discover the plant or animal substances to which sufferers from asthma or other "allergic" conditions are sensitive.

It has been possible to distinguish in the laboratory thirty-five or more distinct types of pneumococcus bacteria that can cause pneumonia. It has been possible to prepare specific serums for a few of these types. But physicians are unable to recognize from the patient's symptoms which particular type of germ is present; and testing for type takes time, and sometimes every hour counts. Before all the types could be readily distinguished, and before dependable serums were available for more than a few types, biochemists had found a more promising treatment. This is the use of the synthetic drugs of the so-called "sulfa" series. These act alike on all types of pneumonia, as well as on gonorrhea and other diseases caused by bacteria of the *coccus* group (see page 613). Individuals differ in their reaction to various sulfa drugs, but research to improve these compounds is going forward

[1]See No. 3, p. 246.

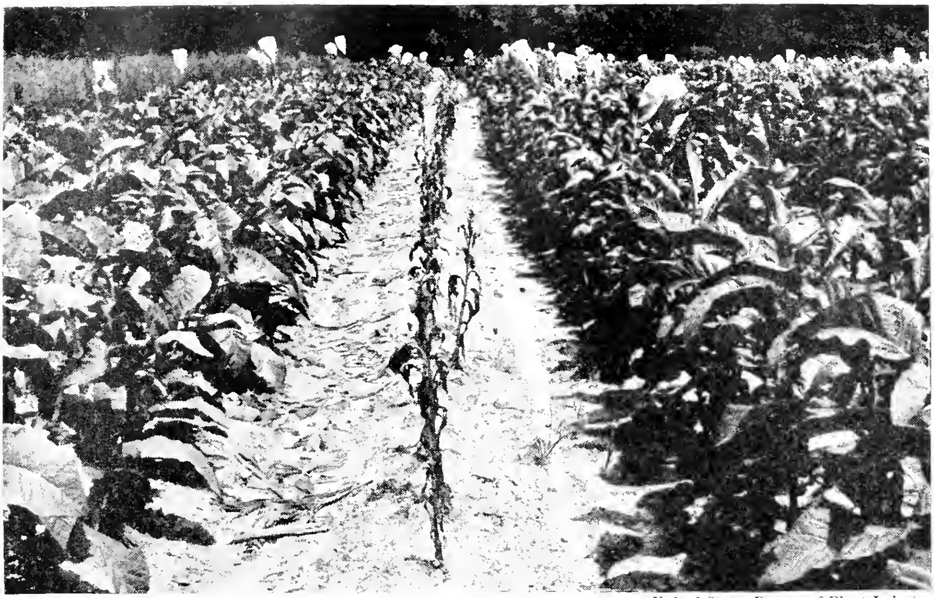


DECLINE OF PNEUMONIA FATALITIES

The general downward trend of fatalities from pneumonia was accelerated in the thirties by the development of special serum "types", and in the early forties by the introduction of sulfa drugs

rapidly. In the meantime, pneumonia, while still a serious disease, is coming to be a less prominent cause of death.

Anaphylaxis In the early days of antitoxin the treatment usually resulted in almost miraculous cures. But occasionally a patient would collapse and die after the injection of the immune horse serum. This baffling reaction was found later to result not from the antitoxin but from a horse protein to which some people are sensitive. Furthermore, if horse serum is used in vaccinating against one disease, and later a horse serum is used in vaccinating against another disease, the patient is much more likely to show this violent reaction, or *anaphylaxis.* By using a sensitivity-test for horse serum the doctor can prevent such a reaction. Various serums and vaccines are now prepared in goats, rabbits, and some other animals, as well as in horses.



United States Bureau of Plant Industry

NATURAL IMMUNITY IN PLANTS

One variety of tobacco was grown between rows of other varieties. All the plants were sprayed with fluid containing spores of black shank, a fungus disease of tobacco. Among plants, as among animals, individuals and strains of individuals differ from others in the degree to which they are susceptible to particular parasites or "diseases"

Immunity and Susceptibility Individual variation includes great differences in sensitivity to particular substances. Some people catch colds more easily than others. Some more frequently have boils or pimples. There are also racial differences. Thus dark-skinned races are less susceptible to malaria and to hookworm than white races. On the other hand, white races are less susceptible to tuberculosis and measles than dark races. Again, human beings are quite immune to diseases that are serious or even fatal to birds or cattle (see illustration above).

Such immunity is called *natural immunity*, and is inherited. In many cases it probably depends upon the chemical peculiarity of the blood. In others it depends upon the quick response of the living cells to poisons or to other products of bacteria. But such natural immunity is not absolute; that is to say, it may be weakened or destroyed by various conditions. The quantities of certain antibodies in human blood can be tremendously increased by the inoculation of suitable foreign substances. This is the basis for the various kinds of artificial immunization, which are popularly called "vaccination".

Carriers We may think of an infectious disease as a process, a conflict between two species. The invader attacks with a small army, which gradually increases in numbers as the parasite lives at the expense of the host. The beginnings are therefore mild, and for a time there is no indication that the host is being injured. When fever and other "symptoms" appear, the host has already begun to react. If antibodies are produced rapidly, the host recovers. Sometimes, however, the host recovers without completely routing the invader. The parasite adapts itself to the chemical conditions of the host, and the host tolerates the parasite: neither appears to be injured. But the germs being discharged from the body are just as virulent when they invade another host. That makes the "carrier" a possible danger to other persons.

The first typhoid carrier on record in the United States was Mary Mallon, to whom seven outbreaks of typhoid fever were traced over a period of years, by 1907. Later 30 other cases were traced to her directly, making a total of 56 cases, of whom three died. She was kept under observation or in confinement for over thirty years, until her death in 1939. As many as 400 typhoid carriers have been under control at one time in New York State. Diphtheria carriers are also watched in a similar way. In such cases the "dangerous" person is perfectly innocent of all wrongdoing; yet he has to be regulated in his activities and movements for the protection of others.

In Brief

Most plants and many of the lower animals can regenerate parts that are injured or destroyed.

Among the higher animals cut and damaged tissues are replaced with scar tissues.

Injured cells apparently give out substances that stimulate the growth of new tissue.

Some poisons stop metabolism; others retard or accelerate it.

Living organisms react to certain drugs in ways that make the protoplasm unable to get along without these habit-forming drugs.

The living organism reacts chemically to foreign substances in ways that are generally adaptive. The chemical changes, usually in the blood, result in antibodies that counteract specific poisons or parasites, so that the body becomes temporarily or lastingly immune.

Serums containing specific anti-substances are used to bring about *passive* immunity.

Immunity to certain diseases can be acquired by recovering from them.

Immunity may also be induced artificially, as in vaccination, by introducing substances that stimulate the blood to *active* production of specific antibodies.

The specific reaction of the body, particularly the blood, to foreign substances makes it possible to recognize, or diagnose, specific diseases and to discover specific immunities and sensitivities by means of serums.

The discovery of serum reactions in the last decade of the past century led to far-reaching changes in the treatment and prevention of communicable diseases, making it possible practically to exterminate some diseases.

EXPLORATIONS AND PROJECTS

1 To demonstrate the extent of regeneration in flatworms (planarians), cut several well-fed worms into two, three or four pieces.[1] Observe them frequently for two weeks to see the extent to which lost parts are regrown.

2 To ascertain whether members of the class are susceptible to diphtheria, arrange with the school nurse or doctor to have each one given the Schick test. What connection is there between susceptibility and age, sex, previous illnesses, general health, vaccinations in the past?

3 To find out about the diagnostic tests used in safeguarding the health of the residents of your community, visit the health department and gather information about its activities.

QUESTIONS

1 How does a wound heal?

2 How do organisms regenerate lost organs?

3 In what different ways do poisons affect the body?

4 How does the action of habit-forming drugs differ from that of other drugs or poisons?

5 How do antitoxins differ from serum preparations?

6 What is immunity? In what different ways can immunity be acquired or induced?

7 Why is it that an active immunity is much more lasting than a passive immunity?

8 What kinds of substances are produced by the body which tend to make it immune to different foreign substances or diseases?

9 Why are the various immunizing serums prepared from several different animals?

[1]Keep flatworms in shallow glass dishes. Feed fresh liver every day or so. Change water a half-hour after each feeding to remove liver not eaten.

We may survey the world of life from the point of view of man or from that of the ameba. In each case we are left uncertain whether the uniformities or the diversities are more impressive and remarkable. Hundreds of thousands of plants and animals differ enough to be kept clearly apart by the observing. Yet they are enough alike to carry on the same basic processes. Cabbages and kings both grow on proteins, fats and carbohydrates. Both depend upon water and air. Both discharge their wastes into the outer world. Both are beset by various parasites. And both, after death, become the food of a million humbler beings.

The naked protoplasm of the ameba is most intimately related to its environment of changing fluid and floating particles. It swallows portions of this environment and assimilates them. Other portions (water, dissolved salts and gases) flow in and out, now faster, now slower, bringing in and taking away. This inward and outward diffusion is determined in part by the nature of the protoplasm and in part by the momentary state of the surroundings. The material condition of living is an interaction of a living unit and the rest of the world; it is a *stream of events* rather than a static combination of substances at a particular temperature.

Living protoplasm is a constant aggression against the environment. It takes from the world a variety of materials which it makes its very own—its very being. The life of an organism consists of building itself up into more and more, and of dodging dangers. The earliest life forms were probably even simpler than the ameba, and they must have been able to transform inorganic compounds into more complex ones by absorbing free energy, as chlorophyl-bearing cells store sunshine energy in carbohydrates.

Getting stuff from the surroundings may be as simple as absorbing fluid or gas by osmosis. We may consider the many thousands of plant species as elaborations of protoplasm more and more specialized in the direction of more efficient capture and storage of sunshine. The elaborations establish communication between protoplasm far from the surface and the outside world. The specializations include transportation systems and supporting systems. A large tree will make tons of wood and bark in the course of raising its leaves aloft and sending its roots afield. The living processes, however, are confined to the protoplasmic contents of living cells. Further elaborations are related to tiding-over periods not favorable to metabolism and to resisting the constant threat of destruction by other living things. Essentially, however, the plant is a system of processes and structures through which the environment is selectively taken in and transformed into more plant. It is a system of maintaining a constant stream of materials through the protoplasm.

Specializations among animals have developed in the direction of greater mobility and of greater sensitivity to what happens in the environment. This involves a greater consumption of materials in the release of energy, as against the mere accumulation of materials in which sun energy is latent. It involves also more rapid exchange of materials between the interior and the exterior. And, in the larger animals, it involves a remarkable combination of (1) rapid transportation of materials through an "inner ocean"; (2) rapid interchange of materials between the several millions of living cells and this ocean; and (3) a high degree of stability, or homeostasis, in the internal fluids.

Specializations in animals are thus related to more complex mechanisms of (1) attacking and taking in outside materials, including oxygen; (2) transforming and distributing these materials to the ultimate consumers in the diverse kinds of cells; (3) collecting wastes and by-products of the cells and tissues and discharging or excreting them. Incidental to these processes are means of locomotion and of defense, as well as of attack; specialized sense organs related to getting food and escaping enemies; and, again, means of resisting or surviving periods during which the ordinary life activities cannot be carried on.

In the highest animals, birds and mammals, the organism supplies its living cells a well-protected and stabilized inner environment, a fluid medium at constant temperature and constant acid-alkaline balance. Materials are continually diffusing into and out of the blood at varying rates. Yet the concentrations of sugar, proteins, fats, mineral salts, oxygen, carbon dioxide, and nitrogenous wastes fluctuate within very narrow limits, regulated by nerves, muscles, and special chemical "messengers", the hormones (see page 304).

The circulating blood distributes whatever heat there is throughout the body and so helps the organism to react to its environment as a whole. It is impossible to have a sick foot or liver and not have the whole body affected. Another remarkable specialization of blood is the rapid mobilization of white corpuscles at points of injury or infection. Other activities are slowed up until damage is repaired.

We may describe the specialized structures and processes of plants and animals in terms of the common activities—food-getting, oxidation, excretion, and so on. It is necessary to keep constantly in mind, however, that the unity of the organism is not a private possession, so to speak. Each species has, indeed, its characteristic details; it has its own way of dealing with the outside world. But these characteristics are related to other living things, and not merely to the salt water of the ocean or some abstract supply of food. To keep whole and to keep going, a plant or animal must carry on certain processes inside itself; but these involve intimate adjustments in dealing with other organisms, both friends and enemies.

UNIT FOUR

How Do the Parts of an Organism Work Together?

1. How can a living thing tell what materials or organisms are suitable for food?
2. How can an animal or a plant distinguish its enemies from harmless organisms?
3. How perfectly are plants and animals adapted to their various ways of living?
4. How does an animal meet an emergency?
5. How do the nerves carry messages?
6. How do plants and the animals without nerves get along?
7. Can all animals learn from experience?
8. Can plants learn from experience?
9. How do living things adjust themselves to changing conditions?
10. How are the different parts of the body made to do teamwork?

Conditions surrounding life are constantly changing. We say that protoplasm is sensitive, for it responds to changes in the environment. But the responses of protoplasm are also adaptive. They are somehow related to preventing injuries or to counteracting them, or to getting for the organism substances or conditions that help to keep it alive. When food gets into the mouth, for example, a new series of movements and chemical actions is started. If a parasite gets into the body, a special series of actions and processes is started. When one runs, the body temperature rises, but the heating and the chemical changes in the blood are then counteracted or balanced. How does the organism meet the changes around it? Sooner or later, we know, most plants and animals starve or are destroyed, for their responses are not always adequate. Some part just misses, or it breaks down.

Mankind is nevertheless impressed by the unity of the organism. Ancient fables try to impress us with the importance of social co-operation by comparing the community to an organism. There is the fable of the various organs that went on strike. The legs remembered that they were carrying the whole weight of the body, but had forgotten that they were being supplied all the nourishment that they could use and were being guided by the eyes and brain. Or the heart complained that it could never take time out, working night and day—forgetting that it could live at all only because the mouth and the stomach and the liver were sticking to their jobs. Such fables are repeated to teach a lesson to ordinary people or to children

who may show signs of being dissatisfied. What indeed would happen if every person were to decide for himself when he would work or how much he would do! If each member of the community attempted to mind his own affairs, and disregarded the common welfare, of course we should all suffer.

This analogy between society and an organism, incomplete as it is, helps us to appreciate one of the most interesting problems in the field of biological study and thought. How does each organ fit its activity in with the activities of all other organs? How does the activity of the whole organism, made up of the activities of the several parts, balance, moment by moment, the demands of the outside world? The eye or the ear catches a hint of something stirring. Is it possible prey? Is it a possible enemy? Is it something to move toward, or something to hide from or to flee from? Of course the animal does not go through this kind of speculation. Indeed, there is no time for that. The muscles and the nerves and the blood-stream do co-operate immediately with the senses and the underlying drive to get or to escape, as the situation may require. Otherwise one would not succeed in capturing his prey or escape his enemy most of the time.

Helpful as is the comparison between the individual organism and society, we must not take our fables too literally. For one thing, no society is ever as perfectly organized as any living plant or animal. For another thing, the individuals who make up our societies, in contrast to the units of an organism, are persons—human beings like yourself, each having his own dreams and hopes and purposes and initiative.

In human society, as indeed in the best adapted of organisms, there is likely to be almost always a degree of maladjustment among the parts. There is dissatisfaction, there is strife, and, sometimes, there is civil war. Co-operation is of course necessary if most persons are to get the most out of life. But it does not follow that each of us is to take what comes without complaint or protest. There are abuses. Some individuals do carry more than their share of the burden. Some individuals do gather in more than their share of benefits. Even in a living body, a heart may be overworked, or a brain may be undernourished. Sometimes surplus fat accumulates where it does no good.

From its very nature, life is a process of change, of constant *re*-adjustment. But from its very nature, too, the several processes of living are related to a central unity. It is in this wholeness, or unity, of the many different processes that life is distinctive. Does life make the parts work together? Or does the working together of the parts bring about life?

1. Are there any conditions in which living things are perfectly adapted?
2. Do all living things make mistakes?
3. How do living things fit themselves to new conditions?
4. Do all living things learn from experience?
5. Do plants learn in the same way as animals do?
6. Do other animals learn in the same way as human beings do?
7. Does the adaptation of a living thing carry over to later generations?
8. Can human nature be changed?
9. Can the nature of other species be changed?

Living means doing, acting. We cannot think of life existing as a pebble on the beach exists, or as a gold brick in a vault. Life is a system of processes. It is related, in one direction, to meeting outside conditions; but it is related, in another direction, to keeping itself going. Life persists through the changes that it brings about.

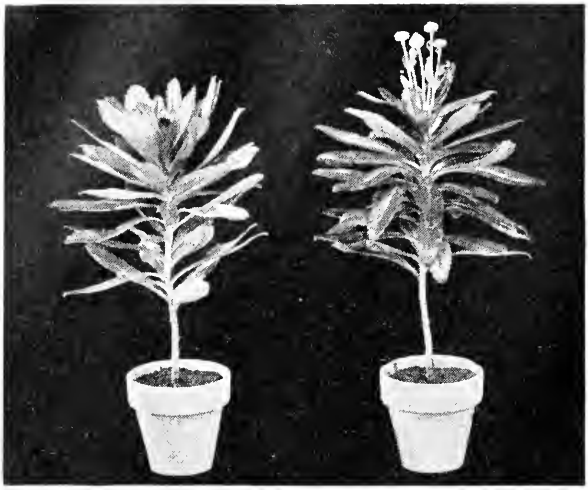
And yet, only to a certain point. The environment in which, and in relation to which, a particular plant or animal lives is itself a changing system. The light changes. The temperature changes. Water vapor and other substances vary in amount. Other living things, also in action, interfere, injure, destroy, although still others furnish food. Plants and animals become diseased. They are poisoned, starved, suffocated. They make mistakes.

How do living things meet new situations? How do they change through experience?

How Do Plants Respond to Changes?

Response to Short Season A crop of wheat in the extreme north, as in Canada or Alaska, will ripen in, say, about ninety days after the sowing. In a more temperate climate the same strain will take four months or more to ripen. The adjustment of the plant to the shorter season is very impressive. How can the plant tell that the frost is going to come earlier in Manitoba than in Oklahoma? Perhaps this adjustment is easier to understand if we attend to the actual facts.

In any given species, such as a particular strain of wheat, developing from the seed to the ripe grain requires a certain amount of nourishment. But this in turn depends upon a certain amount of sunshine. From our knowledge of the earth and its movements, we can understand that one hundred days in the short season of a northern region have, on the average,



P. W. Zimmerman and A. E. Hitchcock, from Boyce Thompson Institute

Plants ripen more rapidly in some regions than in others. These two chrysanthemums were grown under identical conditions except that the one on the right was shaded with black cloth from 4.30 P.M. every afternoon, beginning the first of August. The shaded plant was in full bloom by September 5, behaving like plants growing where the days are relatively short in late summer. The other was then just beginning to form buds

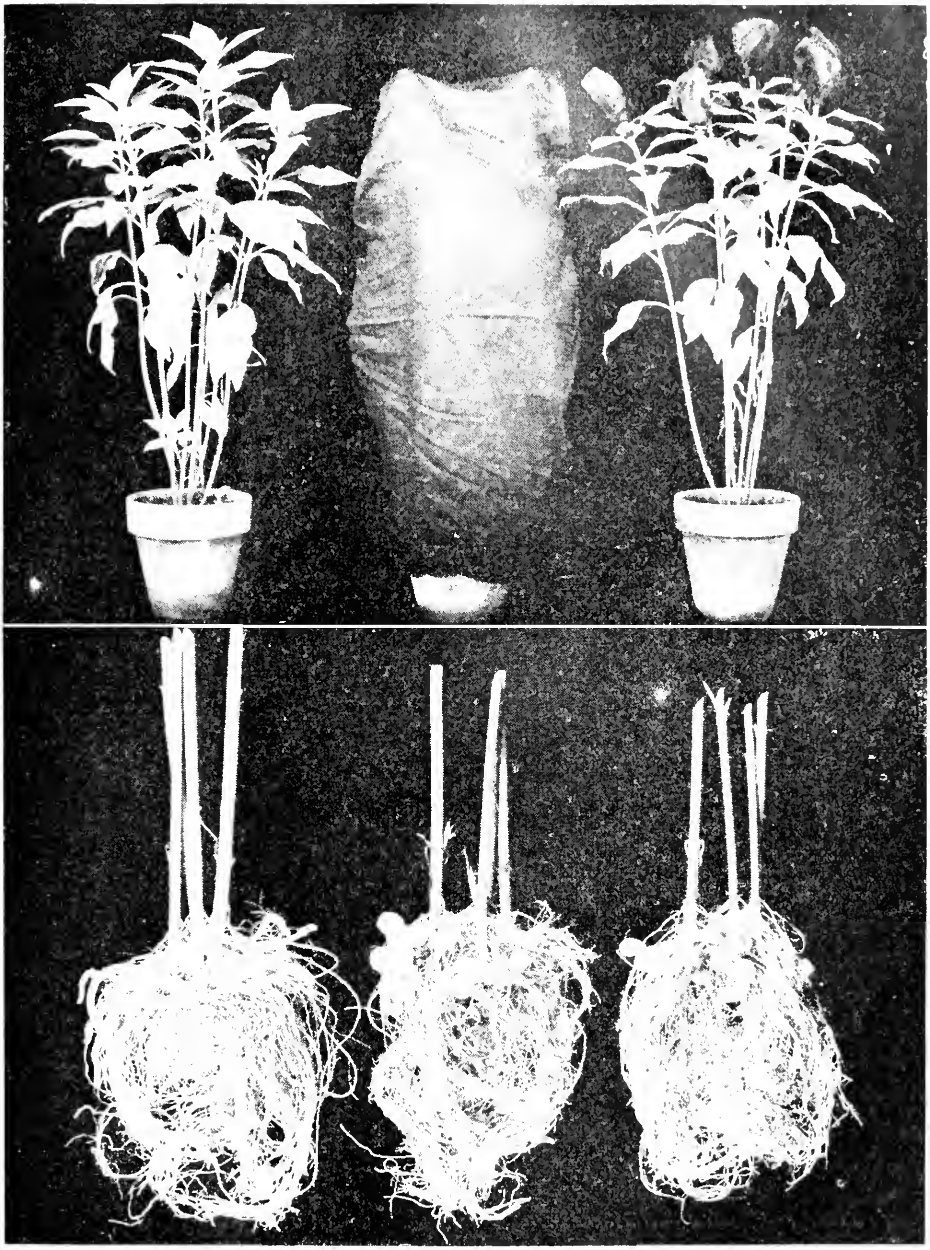
DO PLANTS KNOW THE CALENDAR?

more daylight hours than the same calendar days in a southern region. In the northern latitude, accordingly, plants need fewer days to receive enough light to complete their growth than they would in a southern region. We may say, then, that if conditions are otherwise suitable, ripening will take place after a certain amount of exposure to sunlight.

Another seasonal adjustment that is related to light is seen in the formation of tubers by the artichoke or in the late blooming of the aster. The plant does not "know" what is going to happen later in the season. But as the nights become longer in late summer, more carbohydrate material moves into underground parts and accumulates as starch (see illustration opposite). By shading an aster plant part of each day we can hasten the blooming.

Illumination and Leaf Growth The leaves near the top of a tall tree (which are constantly exposed to light) are generally smaller and greener than those in the lower and shaded portions. This is a definite response to differences in light. If we examine cross sections of the leaves with a microscope, we find that there is much more chlorophyl in the smaller leaves. Although the leaf can make more food in the light than in the shade, *it apparently grows more rapidly in the shade.* In accordance with this fact, the tree seems to fill out its leaf surface to the best advantage (see illustration, p. 254).

Changing Illumination All who have had a chance to observe either house plants or garden plants have been impressed by the fact that the leaves face the light, and that stems *bend* toward the light. If we turn the plants in the window halfway around, we shall find on the following day that the leaves have actually turned to face the light again. If we keep a



P. W. Zimmerman and A. E. Hitchcock, from Boyce Thompson Institute

RUSHING THE SEASON

The artichoke normally starts to form tubers late in the summer, when the nights become longer. By shading the entire plant, or the tips of the stems, from the sun in the latter part of the day, from the middle of July, we can get it to form tubers several weeks earlier than its unshaded neighbors

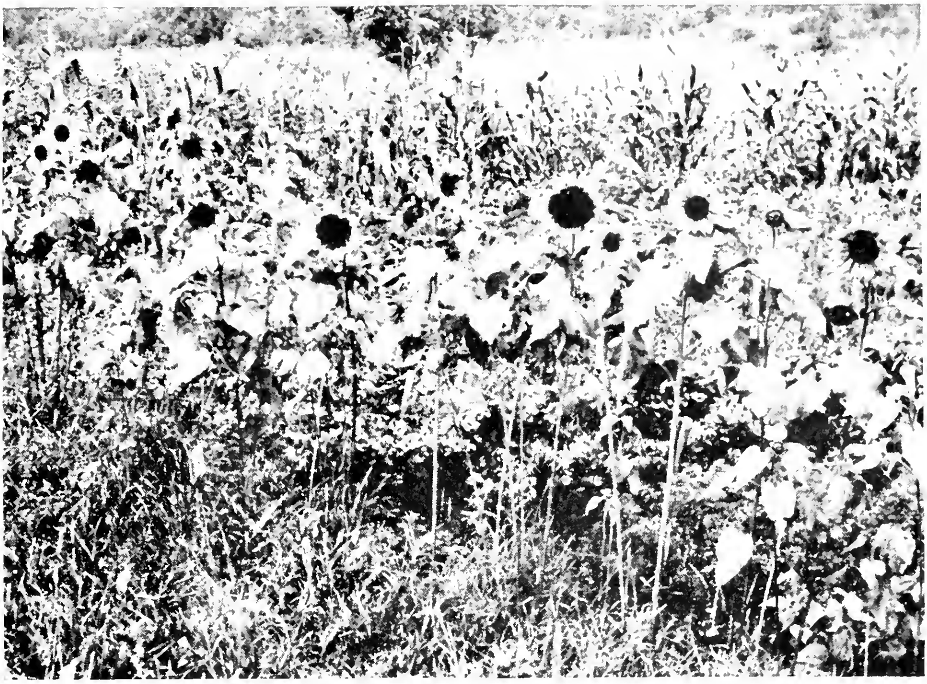
FOLIAGE AS A LIGHT BARRIER

This maple presents a mosaic of nearly continuous leaf surface exposed to the sun. Inside its canopy of leaves, very little skylight filters through between leaves; and we see that very little leaf surface is shaded from the light by other leaves

young plant in a dark closet, we shall find after a few days that the tip has been growing toward faint light coming through the keyhole. What makes leaves face the light? Do they somehow "know" that light is necessary for photosynthesis and so turn to it? Do they like the light?

Water Changes Since roots absorb water (and mineral substances) from the soil, the work they can do will depend upon moisture conditions. Now we know that if there is relatively little water in the soil, roots will go down deeper, into the moister layers of earth. From experiments we can see that roots will change the direction of their growth according to the side on which there is the greater humidity.

Up and Down No matter which way seeds fall upon the ground, if they sprout at all the stem grows upward and the root downward. If an ordinary plant is placed in a horizontal position, the tip of the stem will bend upward, and the root will bend downward. What makes the root grow downward and the stem grow upward? These questions have been fairly well answered by experiments conducted on many plants, in various countries, over a long time.



IS THE PLANT A RUBBERNECK?

Like other species of plants, the sunflower turns its head toward the sun. The leaves also move, facing east in the morning, south at noon, and west late in the afternoon. In no plants, however, can we find anything to correspond to the muscles by means of which we turn our heads to face now in one direction, now in another

Fitness The tendency of the root to grow downward will, on the whole, bring the roots of plants into the soil, where the conditions for getting water are more favorable. The responses of the shoot to gravity and light are likely, in the long run, to bring the plant into situations favorable to its further development. But it does not follow that everything a plant does is to its advantage. Nor is it clear just how the plant brings about these adaptive movements.

How Do Plants Bring About Their Adaptive Movements?

Light and Growth[1] We know very well that growth depends upon food. We have also learned (see page 138) that green plants make their food in daylight. Yet we can easily establish the fact that seedlings and other plant structures grow more rapidly in the dark than in the light. It is not so easy to show how darkness, which is a negative condition, or an

[1]See No. 1, p. 270.

Boston Sewer Division

POPLAR ROOTS REMOVED FROM A SEWER

Roots of willows, poplars and other plants have been known to grow hundreds of feet in the direction of relatively abundant moisture in the soil. Some cities prohibit the planting of poplar trees along the streets because they tend to fill the sewers with their roots

absence of something, can make the stem grow faster. Or is it possible that the *light actually restrains the plant's growth*? In any case, the *unequal* growth of the two opposite sides of the stem would explain the turning of a plant toward the light.

Tropisms[1] The bending of a plant in response to the action of some external force has been called a tropism, from a Greek word meaning "to turn".[2] The turning of a plant axis (or any other living organ or organism) in response to illumination is called *photo-tropism*—that is, "light-turning". Similarly, we apply the name hydro-tropism to the response of a plant or plant part to water. The stem and the root are said to show geo-tropism, or earth-turning, under the one-sided influence of gravity. A plant sometimes

[1]See No. 2, p. 270.

[2]The root of this word is the same as that of the word *tropic* used in geography. The Tropic of Cancer and the Tropic of Capricorn were the astronomers' time points in the calendar when the sun turned back in its apparent north-and-south migrations in the seasonal cycle. The tropics are the regions between these two turning-points; that is, they are the latitudes in which the sun is directly overhead at some time between one turning and the next.

responds in the direction *from* which the stimulus or disturbing factor comes to it, and sometimes in the opposite direction. We distinguish tropisms accordingly. The turning of leaves and stems toward the light we call *positive* tropisms, whereas the bending of the stem away from the direction of gravity we call a *negative* tropism.

These are convenient terms, but we must not let them mean "for" or "against" in the sense in which we speak of our own likes and dislikes or our attitudes in a debate. Nor must we suppose that these terms in any way *explain* what happens. They are convenient for summing up the facts that nearly everybody can observe for himself. We are still in the dark as to how these delicate and adaptive changes are brought about, even when we call them changes in growth.

Growth Substances[1] In 1927 Frits Warmolt Went (1903–   ), a young Dutchman who came to the California Institute of Technology, succeeded in answering partially the question, What besides food or temperature affects the rate of a plant's growth? He cut off the tips of young oat

If we keep some sprouting potatoes or seeds in the dark and others in the light, we find that those in the dark grow faster. Farmers remove seed-potatoes from dark cellars and spread them out in a lighted shed to prevent the growth of long sprouts

L. P. Flory, from Boyce Thompson Institute

Plant loves light and bends toward it. Light attracts plant. Shaded side grows faster, bending stem toward light.
Do these statements all mean the same thing?
Do they equally describe what we can see?
Which most agree with the facts?

L. P. Flory, from Boyce Thompson Institute

LIGHT AND GROWTH

[1]See No. 3, p. 271.

seedlings and found that the remaining portion quickly stopped growing. If, however, he replaced the tips immediately, the growth was not greatly retarded. Does something in the tip move into the growing region and there stimulate growth? To answer this question, he removed some tips and placed them on a small piece of agar (a substance similar to gelatin) for a short while, hoping thus to soak out the supposed something. Then he touched this agar to the original cut stumps of the oat shoots. The effect was the same as that of replacing the cut tips, whereas ordinary agar blocks did not stimulate growth (see illustration opposite). Apparently some substance passed from the tip into the agar, and then from the agar into the cut stumps. Apparently growth occurs only when this unknown substance is present. Because this substance stimulates growth in the plant, it was called *auxin*, from a Greek word meaning "to grow". Because it influences metabolism as do certain animal secretions, we call it a plant *hormone* (see pages 303–304).

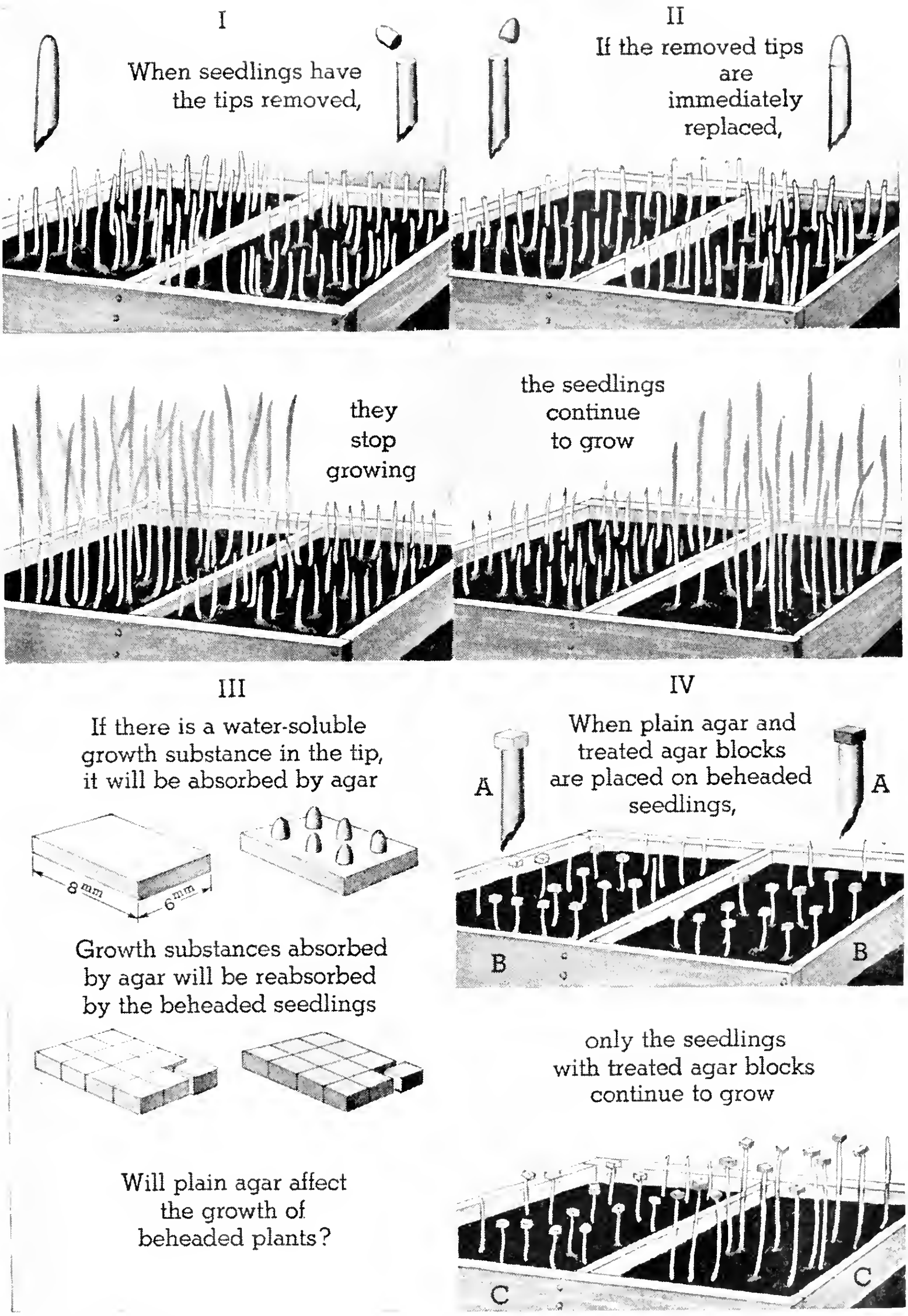
But what is the connection between an auxin and a plant growing faster in the dark? It was known that if the tips are cut from young seedlings, the stalks do not respond to light. Is more auxin present on the shady side of growing stems than on the lighted side? Does light in some way destroy or repel this substance?

One investigator separated the lighted halves and the shaded halves of hundreds of growing stems into two piles. From the shaded halves he extracted more growth-stimulating substance than from the lighted halves. Apparently an auxin makes the shaded side grow faster. But why is there more of this substance on the shaded side?

This question we cannot yet answer. We may feel certain, however, that a plant responds as it does to light because of chemical changes going on within. The plant is obviously as unaware of these changes as you are of the increased quantity of oxygen in your blood after it has traveled through the capillaries in the lungs.

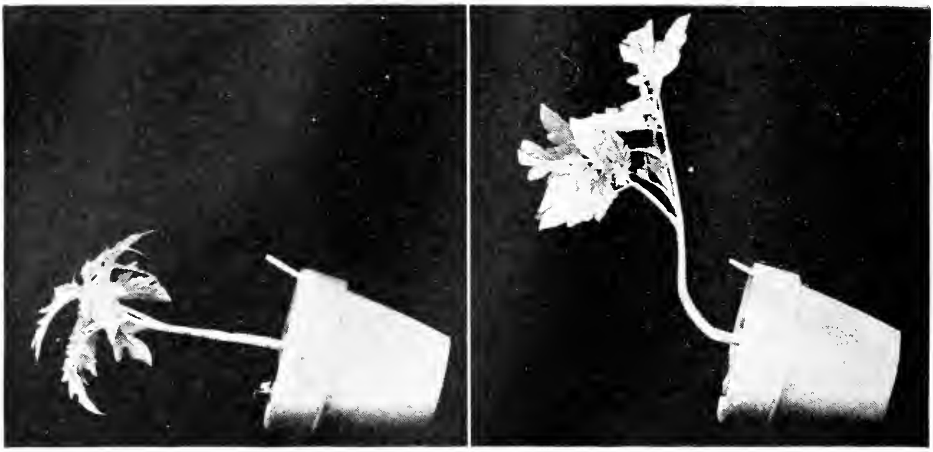
Geotropism and Auxins In order to find out whether a hormone controls geotropism as well as phototropism, scientists placed growing stems in a horizontal position. They found that the cells on the lower side contained more auxin than those on the upper side. If a growth substance makes the lower side of a horizontal stem grow faster, then the tip will bend upward. But we do not understand why the auxin moves toward the lower surface.

Chemists have produced several compounds that behave in many ways like the natural auxin. One of these, indole-acetic acid, counteracts the natural auxin (see illustration, p. 261). From such experiments it is reasonable to conclude that the growth and the form of the plant, as well as some of its tropisms, are determined by chemical substances having particular arrangements of atoms in their molecules.



GROWTH SUBSTANCE

How can we tell that there are special growth substances? Experiments show that a substance formed in the tip of the shoot stimulates the growth of the plant



P. W. Zimmerman and A. E. Hitchcock, from Boyce Thompson Institute

NEGATIVE GEOTROPISM IN PLANTS

Stems of most plants tend to grow upward, unless forced or disturbed by some outside agency. Is the tomato's turning away from the earth connected with the formation and distribution of growth substances? If it is possible to remove auxins from the tips of oat seedlings, is it possible to remove auxins—if any—from the lower or upper halves of the horizontal tomato stem?

Further experiments showed that this "artificial auxin" counteracts plant auxin in the normal negative geotropism of stems (see illustration opposite). From these experiments we may conclude that auxin and indole-acetic acid have essentially the same effects in stimulating growth-responses to light and to gravity. Chemists have found certain similarities between the chemical make-up of natural plant auxin and that of several synthetic compounds which all have the same effects on plant growth.

Do Animals Respond to Stimuli Automatically?

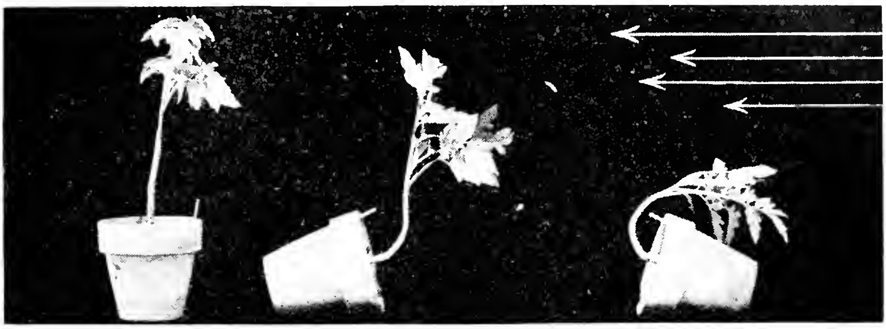
Animal Tropisms[1] Fruit flies and common houseflies turn toward the light. Earthworms turn away from strong light, but toward a very weak light. Such turnings usually involve the whole organism rather than merely a single organ or portion. On summer evenings we can see swarms of insects, usually several different species, around any street lamp or other exposed light. Insects in large numbers often get stuck in the radiators of motorcars driving through the country at night. Lighthouse-keepers report that hundreds of birds dash themselves against the windows and get killed, especially during the migration periods.

These tropisms of animals are unlike the growth-movements of plants, for they are brought about by the contractions of special portions—the

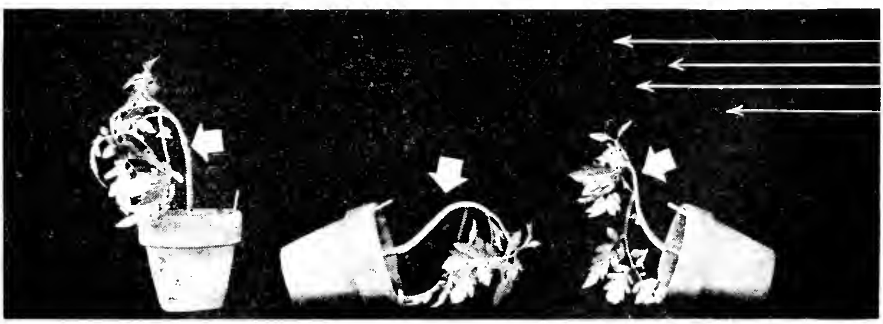
[1]See No. 4, p. 271.

Tomato plants laid on their sides, with the light coming from the right,

turn their tips upward, and also toward the light



If now the lighted side in the erect plant and the upper sides in the horizontal plants are treated with indole-acetic acid,



the plants bend away from the light and also turn downward

P. W. Zimmerman and A. E. Hitchcock, contributions from Boyce Thompson Institute

RESPONSE OF PLANTS TO LIGHT, GRAVITY AND GROWTH SUBSTANCES

Is the tomato plant's turning toward the light and away from the earth determined by auxins, or growth substances? Is it possible to remove auxins — if any — from the plant? Both extracted auxins and synthetic compounds reverse the plant's responses to light and gravity. Can we change the behavior of animals by chemical means?

muscles—in all but the simplest animals. But they resemble the plant tropisms in that they take place automatically, or mechanically. That is, they are in no way voluntary, or controlled by a "will". From the fact that the moth flies to its own destruction we may at least argue that there is no *intention* in the act. Although the animal has a very good set of compound eyes and a comparatively complex nervous system, it seems to have no choice.

Responses to Gravity Whatever "gravity" is, it acts upon animals and plants, as well as upon stones and planets. Some animals adjust themselves to the action of gravity in a variety of ways that are tropic, but not all. The housefly, for example, seems to be indifferent to the direction of gravity; it will crawl upon a surface in any plane and in any direction, and it will come to rest in any possible position. Yet, if you place a fly on its back, it will right itself, as would a backboned animal or a starfish.

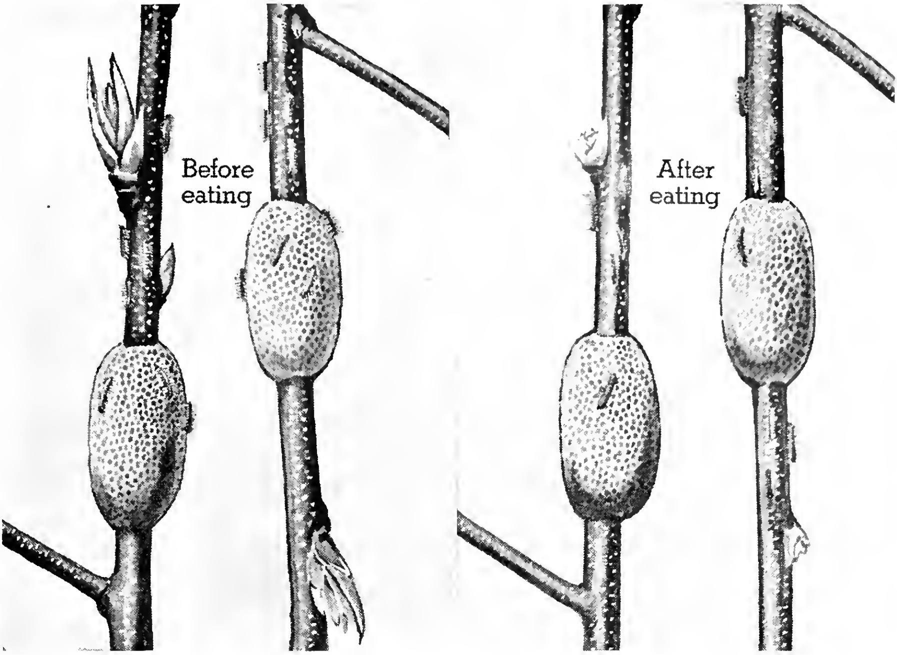
Many adult insects, when they alight on a tree, assume a position with the head pointing upward; other kinds always rest with the head pointing downward. In still other species, the source of light determines the position, rather than gravity. In some species the young larva crawls toward the tip of the twig. This movement is adaptive since it brings the young insect to its food. But in some species the animal moves toward the light, whereas in others it moves up, as we can tell by experimenting.

Some of the simple marine animals appear to be influenced by both light and gravity. Certain species of minute crustaceans swim near the surface only at night; under the influence of light they become *negatively* geotropic —that is, they swim down from the surface. Experienced fishermen have learned that many species of fish are to be found at varying depths according to the time of day: in a given lake, however, at a given hour, hundreds of fish of the same kind will be found at about the same level. There is probably a combination of influences at work—temperature, as well as light and gravity. And many of the variations in an animal's reactions appear to result from changes in the chemical or physical state. The larvae moving toward the tip of the twig show a *reversed* tropism after they have eaten.

Reflex Action When you are tickled, you draw away the touched part. When something approaches your eye, you wink. A slight touch inside the nose leads to a sneeze. A solid particle on the lining of the windpipe makes you cough. When you place a solid in a baby's palm the hand closes down. Such reactions to particular stimulations have always been known. In the members of any species of animal they are remarkably uniform. And in any individual they are remarkably constant.

A famous French philosopher and mathematician, René Descartes (1596-1650), suggested for this type of action in animals the name *reflex*. It is as if a force entering the body at some point—the skin or the eye, for example

GEOTROPISM IN LARVAE OF TENT CATERPILLAR



When larvae first hatch out of the eggs, they move up—toward the tips of the twigs, where leaf buds are opening. But if the twig is bent over, they still move up — away from their prospective food

After their first feeding excursion, the larvae move down—away from the tips—to a crotch, where they spin a "tent". But if the twig is bent over, the larvae still move down—toward the tips of the bare twigs

DO THE LARVAE KNOW WHAT THEY ARE DOING?

The young larvae normally move toward the young leaves when they are hungry and away from the leaf buds when they have filled up on food. But apparently they move up or down under different internal conditions, even at the risk of going hungry

—were "reflected" into a muscle. The nature of the force and the actual connection between the stimulus and the response were not worked out for nearly two hundred years. The idea was a helpful one, however, and the term *reflex* remains in use.

And we make use of the fact too. For if you ever catch a fish with hook and line, your success depends upon a reflex. The fish responds to the sight of certain kinds of objects by snapping at them with its mouth. If the conditions are suitable, if you have the right kind of bait, if it is properly fastened to the hook, and if you drop it into the water at a suitable depth, your "luck" depends upon the presence of the fish and his *seeing* the bait. The reflex does the rest. This appears to be a mechanical act, like a tropism. We cannot

assume that the fish means to get caught, any more than the moth **intends** to get singed in a flame. Neither can avoid acting as it does.

Human Automata Winking, sneezing, coughing, swallowing and other familiar reflexes take place in the human organism in direct response to some stimulus. They are acts that take place without being intended or desired. They take place in practically the same way in all members of the species, and, generally speaking, *they cannot be prevented.* Human beings, like other living things, sometimes act like mechanisms.

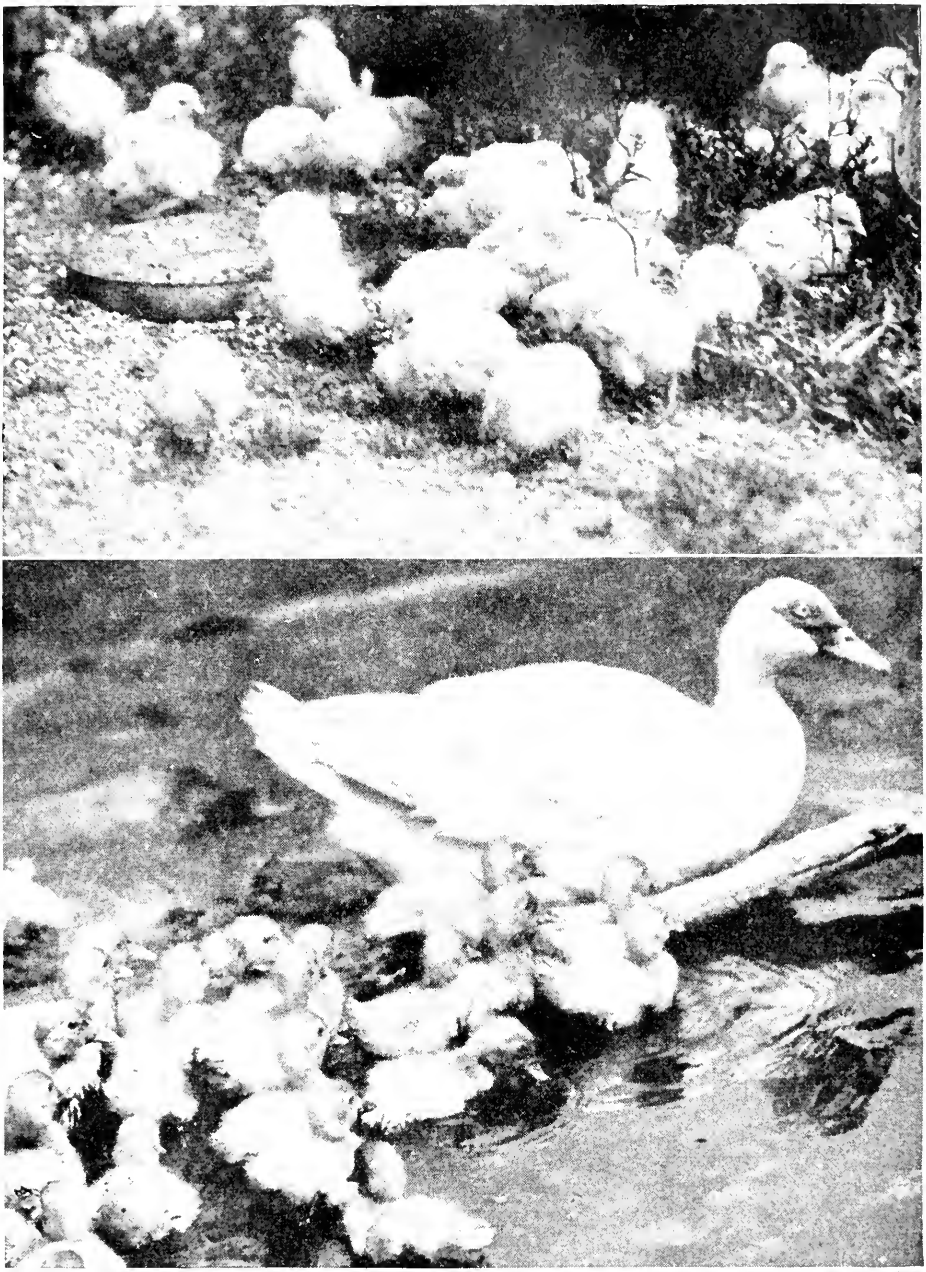
A different type of automatic response that is at the same time adaptive, or helpful in keeping the organism going, we have already considered in connection with homeostasis (see page 194). When you increase your muscular work for any purpose—moving furniture about, climbing stairs—your heart begins to speed up, your breathing changes, your kidneys begin to work faster. Some of these alterations are more like plant responses, resulting from chemical and physical interactions. Speeding up the respiration rate, however, is a reflex: this is set up by a chemical stimulation (increased concentration of carbon dioxide in the blood) upon a certain nerve center.

Our reflexes do not always show themselves in movements. When the "funny bone" is struck, for example, we become aware of a tingling sensation in the palm of the hand. This is apparently due to the reflex contraction of small skin muscles, which in turn stimulate *sensory* nerves. "Watering of the mouth" is a gland reflex to an odor stimulus.

Reflexes and Tropisms Reflex action differs from the tropic movements of plants in being usually much more rapid, and in resulting from a different kind of structure, or mechanism. Reflexes depend upon nerve cells and nerve connections, and the movements themselves involve muscles—two kinds of cells that we do not find in plants.

To say that a reflex act is like the movement of a bell clapper when the right button is pushed may seem to belittle human conduct; nevertheless the statement appears to be true. However, we must not read it to mean that human action is "nothing but mechanical", for each reflex is but a fraction of human behavior, and there is much more that cannot be described or "explained" as mechanical.

Instincts When a baby is touched on the cheek near the mouth, he turns his head to bring his mouth toward the point of contact. When an object touches his lips, the baby usually opens his mouth and grasps the object. When something gets into the mouth, the touch stimulus sets up the sucking movements. When something touches the back of the throat, the stimulus starts the swallowing reflex. Here is a *chain* of reflexes which together bring about adaptive action. We can show that each step is a reflex by setting it off independently of the others.



Lynwood Chace

UNLEARNED CONDUCT IN YOUNG ANIMALS

Young chicks, pecking at food or walking about, perform these acts about as well the first time as later. Baby chicks or ducks follow the mother about, and that seems a useful, or adaptive, "instinct". Apparently they would follow many other moving objects of about the same size

Many of the so-called instincts in animals are either simple reflexes or combinations of reflexes. It is characteristic of many of the adaptive and useful activities that they are *not learned.* Young chicks, for example, pecking at food or walking about, perform the acts about as well the first time as later. Moreover, all the members of the species normally act in the same way. Apparently instincts depend upon special sets of structures that are characteristic of the species. Yet we know that animals do change their instincts.

How Do Organisms Change through Experience?

Changing Instincts A pike was placed in an aquarium with a number of smaller fish. The pike swallowed his neighbors. A glass partition was then put in, separating the pike from the smaller animals. The pike would dart at them, however, and was often stunned by striking the glass plate. But in time he stopped darting after the small fish. Later the partition was removed. Yet the pike always turned aside when he approached one of the little fellows. Nothing now prevented his eating them *except his past experience.* That is to say, his natural behavior had become modified.

The bruised pike shuns small fry; a burnt child dreads the fire. Acts which have unpleasant accompaniments come to be avoided. Certain natural impulses become repressed. On the other hand, acts associated with feelings of satisfaction come to be performed more readily. This is the principle that you would use if you tried to teach a dog or a colt a new trick. If you reward the animal with praise or a piece of sugar every time it does what you want it to do, it will be more likely to repeat the performance. At last the acquired trick takes the place of the animal's earlier spontaneous behavior.

A baby crying for food will at first keep on crying until something actually touches his mouth. In a few days he stops crying as soon as he hears his mother's voice. Some will say that the child "recognizes" his mother's voice, or that he "knows" that she is about to feed him. But from observations and experiments with the young of many animals, including babies, we say rather that the sound has become associated with the feeding. And this association of two experiences has modified the natural response. A new stimulus—in this case, a particular sound—now acts as a substitute for the original stimulus to stop the crying or to start the sucking. This new mode of responding, the new trick of behavior, is sometimes called a *habit.* This familiar word habit is commonly used in a broad (and not always a very exact) sense. But from experiments with many animals, including human beings, we have learned a great deal about how conduct is modified.

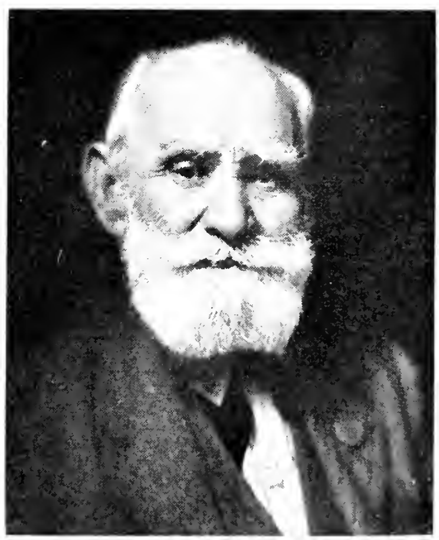
Conditioning The most famous and extensive of these experiments, mostly with dogs, were directed by the Russian physiologist Ivan Petrovich Pavlov (1849–1936). They started from the well-known fact that a dog's

mouth "waters" when meat is offered him. But the mouth does not always water: a dog that has just finished a good meal, for example, behaves differently. The chemical condition of the body's juices seems to make a difference. At any rate, Pavlov arranged a tube inside the dog's cheek to collect the secreted saliva; and then he took the amount of saliva delivered to indicate, or measure, the dog's response to a particular stimulus. Since it was found that the dog's response—saliva secretion—varied with the condition of the animal's nutrition, the experimenters then used dogs in a "hungry" state.

Now in one series of experiments some special stimulus was combined with the feeding. For example, just before the meat was presented, a bell would be sounded, or a light would be flashed, or the dog's name would be called. After a number of such experiences—more with some dogs than with others—the animal's mouth would water as soon as the stimulus acted, before he saw or smelled the meat. Later, dogs were taught to discriminate between different lights or colors or sounds. For example, the note G on a piano or tuning-fork was sounded every time the animal was fed. At other times, a different note—say G sharp—was sounded, but unaccompanied by food. After a period of training the dog would secrete saliva when he heard G, but not when he heard G sharp. In these cases a new stimulus—the note G, or a flash of light, or a particular color—acted as a substitute stimulus for setting up saliva-secretion.

We can see some resemblance between the modified behavior of animals and the tricks which dogs and horses and other animals "learn". But Pavlov

Pavlov started his famous researches that developed the idea of "conditioned reflex" with experiments on secretions of the digestive system. Such secretions are sometimes started by stimuli that are not directly related to food. Your mouth waters when you see food through a window, or even when you read about food. How does that happen? Do other animals secrete juices without relation to immediate food conditions? Pavlov tried to measure the reflexes by measuring the amount of saliva secreted by a dog under different conditions. His work started with a dog that had been wounded in the stomach, and has had a great influence in furthering research, and in interpreting human behavior, as well as animal behavior



IVAN PETROVICH PAVLOV (1849–1936)

and his associates were careful to avoid the idea that such changes correspond to what happens when one of us "learns" any kind of lesson. Indeed, Pavlov is said to have penalized any workers in his laboratories who used the word *learn* in connection with these experiments.

Such conditionings were carried out in very complex combinations. For example, the dog's food would be placed at a certain point in the room, and the dog in time came directly to that location. Then a special stimulus preceded his admission to the room, until that signal came to mean for the dog "come and get it". A different stimulus preceded an electric shock, which made the animal turn and run away. These two "signals" thus became associated with coming and going. But they were also substituted for the stimulus "see meat", so that seeing meat no longer made the dog's mouth water. Now the conditioned dog had to come *or* go when he saw meat, but he had to wait until he saw which signal was up (see illustration, p. 671).

The natural responses of many birds and mammals and other animals have been conditioned experimentally. Even an earthworm can be conditioned to turn always in a certain direction for food.

By feeding and milking cows on a regular program we get them to come in from pasture at sunset or when we call them. This saves the work of going after them. Horses come to follow fixed routes, and they come home after they have strayed away. Chickens come in response to a familiar call. We train animals to perform tricks for our entertainment.

Learning and Feeling The experiments show us that conditioning is not merely a matter of repeating and repeating: it involves the satisfactions or pains that are associated with experience. Indeed, this has always been generally recognized and used in the training of animals. Nearly everybody recognizes this principle to some extent; we encourage one kind of conduct with rewards, and we discourage other actions by means of punishment.

All this works well enough in laboratory experiments or in training animals. But it presents some difficulties when we are dealing with human beings. Most of us are intelligent enough to discover that we can obtain certain rewards for doing what others demand of us. One hates to practice scales, for example; but he can stand the annoyance for half an hour in exchange for candy or a visit to the movies. But unless the "practice" yields other satisfactions, he seems to make no headway. Or one may learn how to dodge penalties provided for disapproved behavior, instead of learning to abhor such behavior.

The education of human beings, like the training of a dog, begins with the changing of natural or impulsive behavior. But human learning, skill and character go much farther and involve much more than training or conditioning. The great differences between man and other species seem to be related to the complex brain and nervous system that distinguish our species.

Training and Education A human infant's behavior is constantly being modified by his day-by-day experiences. His impulses and his desires become modified, as well as his ways of carrying out his impulses, his ways of satisfying his desires. But we attend chiefly to what the child *does*, rather than to what he feels or needs. So we drill children and adults into standard ways of acting in many routine situations, in many types of skills. We try to establish good manners or correct form to cover almost every hour of the day. All these habits and learnings may be useful, but only in repeated situations and relationships.

No scheme of fixed habits can fit a human individual for an entire life, unless he is to remain an infant or a slave, directed entirely by others. Since each person is himself altering the world for those around him, all of us have constantly to meet new situations, new problems, new relationships with others. In civilized, democratic living, each of us must of course do well whatever he has to do. We must acquire special skills, master a thousand tricks. But we must also be prepared at any moment to do something we have never done before, to take initiative, to make decisions—to break routines.

For these reasons, habits must be subordinated to sound attitudes and judgment. In human affairs it is more important for the individual to care, to feel responsible, to be concerned—to care about traffic safety, for example, and not merely fear being caught by the traffic police. It is more important for one to be true to himself, to what he considers of greatest worth, than to be clever in avoiding detection. In educating for human living training is necessary; but more and more is it necessary to develop the feelings in relation to what is desirable or worthy—to develop sound attitudes toward people and things.

Adjustments Living things adjust themselves to their surroundings in many different ways. Apparently they can tolerate considerable variation in the conditions that surround them—more or less moisture, light, mineral salts, higher or lower temperature. But always there is a point beyond which too much or too little is fatal. The protoplasm adjusts itself by slowing its action or hastening it, or by changing the rate of some processes more than that of others. Among more complex animals the nervous system plays an important role in bringing about particular movements, in retarding or accelerating processes.

In general, however, life carries on by interacting with the environment. It receives stimuli and it reacts. It receives materials, and it returns other materials. It distributes materials among its own parts; it distributes stimuli and reactions among its own parts. These interchanges of materials and energies are balanced within the organism. And they are balanced as between the organism and the outside world. But the balance is never quite perfect.

In Brief

The behavior of plants and animals appears to us as the fitting of organisms to the conditions under which they live; of course those organisms which fail to fit the conditions soon cease to exist.

Some of the adjustments which living things make to their environment are fixed in their structure and development.

Other adjustments appear to be the result of experience or of exposure to new conditions.

Plants show turning, or tropic, responses to gravity, water and light; these appear to result from specific alterations in rates of growth.

The bending of a plant toward the light is due to unequal growth, the more rapid growth taking place on the darker side. The differential growth appears to result from the action of light, which decreases the amount of auxin, or growth-stimulating substance.

The more we study the remarkable adjustments of living organisms to their environment, the more of these adjustments do we find to be automatic: the organisms cannot help responding as they do.

Each particular kind of protoplasm thrives best in a particular set of conditions; yet each is capable of adjusting itself to conditions that are somewhat different in one detail or another.

The behavior of many species of animals in response to stimuli can be conditioned or modified into new forms and patterns.

Education consists in part of forming appropriate patterns of action or avoidance. Habits are useful in doing things that have to be done in the same way over and over again.

Practice is effective in establishing habits when it is associated with strong feelings.

To meet new situations habits have to be subordinated to sound attitudes and intelligence.

EXPLORATIONS AND PROJECTS

1 To observe the effect of light on movement within a cell, place a leaf from the tip of a rapidly growing elodea on a slide and examine under the microscope (use high power). Increase the intensity of illumination on the leaf by adjusting the mirror so as to direct sunlight on it. Note effect on the streaming of the protoplasm inside the cell.

2 To study the growth movements, or tropisms, of plants:

To find the relation of light to the direction of growth, place a pot of rapidly growing seedlings under one-sided illumination; allow it to remain undisturbed for several days. Note the position of stems and leaves at the start, and again later.

To find the effect of light upon the growth rate in plants, place one of two pots of growing seedlings or of sprouting potatoes in a light room and the other in a dark closet. Keep all the conditions except the intensity of light the same. Compare growth after a few days. Record differences and account for the results.

To find the relation of gravity to the direction of growth of roots and shoots, place several soaked seeds on moist blotting paper between two large panes of glass so that they may be observed. Fasten the panes in vertical position with bottom edges resting in a tray of water. With a wax pencil mark the positions of the roots and of the shoots when they appear. Then turn the arrangement one fourth of the way around and allow to stand in tray for two days more. Mark the position of each shoot and each root daily. Turn the arrangement one fourth of the way around further and again mark positions of roots and shoots. How do the roots and shoots respond to the shifts in position?

3 To find the effect of growth-modifying substances on the growth-response of plants to light, place several vigorous potted plants of the same kind in a window and apply the material to all but one of them, on the side of the stem exposed to the light.[1] After a week or so, compare the plants for any difference in growth.

4 To study the responses of organisms to stimuli, observe the behavior of paramecia through the microscope, while changing the physical and chemical conditions surrounding them.[2]

To find the response of paramecia to changes in temperature, bring into contact with the slide on which the animals are mounted a clean slide that has been heated by moving it back and forth above a low flame, and watch the animals as they are slowly warmed. Cool the slide by placing an ice cube on one end of it. How do changes in temperature affect the behavior of the animals?

To find the response of paramecia to acid, place a drop from a test tube of water through which carbon dioxide has been bubbled (from the lungs or from a generator) near the drop in which the paramecia are swarming. Draw the two drops together with a pin and note the changes in the behavior of the animals. Describe the response. How can this response be related to the animal's method of getting food?

To find the response of paramecia to electricity, place about 50 cc of the culture in a shallow dish, and at opposite sides of the dish insert two carbon rods that are attached by wires to the two terminals of a 6-volt battery. Describe the reaction of paramecia to the electric current. Do they migrate equally toward both poles, or away from both poles, or toward one pole and away from the other?

[1]Use indole-acetic acid or naphthalene-acetic acid as growth substances. Prepare mixtures in following proportions: (1) 10 mg growth substance to 1 g lanolin; (2) 2.5 mg to 1 g; (3) 0.6 mg to 1 g; (4) 0.15 mg to 1 g. Dip a glass rod into each preparation in turn and touch it to side of stem of one plant.

[2]Prepare a hay infusion by tying a double handful of hay in a cheesecloth bag and suspending it in a gallon jar of water. After this has rotted for one week, add some water collected among vegetation along the edge of a pond. In about two weeks the top of the hay infusion should be teeming with paramecia.

1 In what sense are the adjustments of living things to their environment fixed in their structure or in their development?

2 To what stimuli do plants commonly respond?

3 How do plants respond to different stimuli?

4 What makes plants grow faster in some regions than in others?

5 In what respects are the mechanical responses of plants adaptive?

6 In what respects are the tropisms of animals like those of plants? different from those of plants?

7 What factors determine whether plants and animals that have been shifted from their natural environment will adjust themselves to the new surroundings?

8 How do various kinds of living things repair injured tissues?

9 How can the native instincts in organisms be modified into new forms of behavior?

10 In what respects are habit formation and education alike? In what respects different? Which receives the more emphasis in the training of animals to do stunts? in the guidance of human beings?

11 In what respects is the behavior of men like that of other animals? In what respects different?

CHAPTER 15 · WHAT DO THE NERVES DO?

1. Are there any animals that have no nerves?
2. How can some animals get along without special sense organs?
3. Do animals feel pain as we do?
4. Are there any activities in the body that we cannot control?
5. What is the use of pain?
6. What is the "funny bone"?
7. Would there be any harm in killing the nerves in the teeth?
8. Are people with larger heads smarter than those with smaller heads?
9. Is it true that if one of the senses is injured, the others become more keen to make up for it?
10. How can we tell whether other animals perceive the world through the senses just as we do?

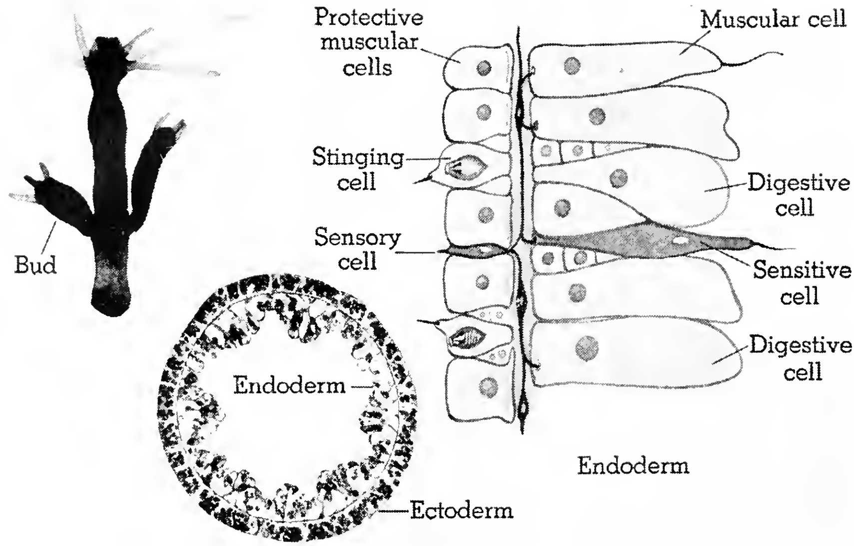
Among the lowest organisms, different stimuli may produce similar effects. Thus an ameba contracts when touched, when suddenly illuminated, when stimulated by some chemical substance or by a charge of electricity. In our own bodies the division of labor is so great that there are several highly specialized organs—the eye, the ear, the tongue, and so on. Each of these is sensitive to only a limited class of stimuli. Moreover, the various organs respond in special ways. Sometimes there is a rather violent reaction through sudden movement. Or a stimulus may bring about a chemical change, as in the formation of an antitoxin or in the increased secretion from a gland.

The most striking feature in the structure of higher animals is perhaps the presence of the nerves. These specialize in receiving disturbances and in transmitting them. How do the nerve cells really differ from other kinds of cells? How do they influence the action of other kinds of cells? How do they make the parts of the body work together?

What Kinds of Cells Are Nerves?

Special Functions and Special Cells In the ameba and other one-celled species each cell carries on all the life functions—feeding and assimilating, breathing and oxidation, moving, excreting, sensing, reproducing (see illustration, p. 23). But the cells in larger plants and animals impress us not with their similarities but rather with their *differences*—as between the bone cell and the gland cell or between the skin cell and the muscle cell.

In each special tissue we find an exaggeration of some special function that is *common to all protoplasm.* Thus chemical processes of various kinds



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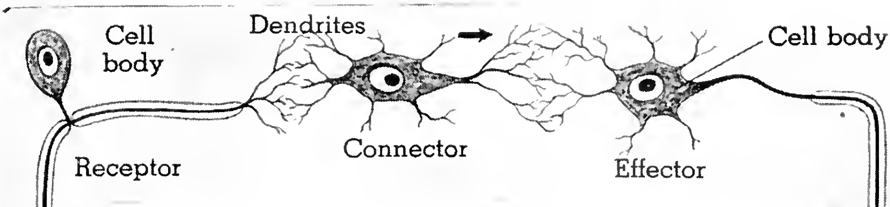
SPECIALIZATION IN HYDRA

In each of the two layers of cells that make up the hollow bag and tentacles of Hydra, there are sensitive "nerve" cells and also especially contractile "muscular" cells. In the outer layer there are also "protective" stinging cells, which dart out fine hollow needles and an acrid fluid when disturbed. Some inner-layer cells secrete digestive fluids

go on in all protoplasm, but in gland cells there is mass production of particular kinds of compounds. All protoplasm contracts more or less, but muscle cells contract more energetically and more extensively than most other protoplasm. All protoplasm is irritable, or sensitive to disturbances, but nerve cells are especially sensitive.

There are, of course, no special tissues or special kinds of cells in the protozoa. But where the cells, as they are formed by the division of the mother-cell, cling together instead of drifting apart, division of labor takes place. Thus, in the poriferans and in the coelenterates (see Appendix A), we can see two or more different kinds of cells.

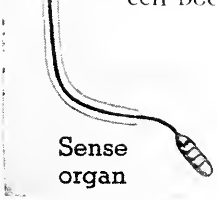
The simplest organism having distinct nerve cells is the hydra (see illustration above). When one of these is disturbed, it does not contract, as does the ameba, but it transmits the disturbance, or stimulus, to all parts of itself and *on to other cells.* It specializes in sensitiveness and in transmitting. Its many branches touch many different cells; its structure suggests a reaching out in all directions. When delicate nerve-endings at the surface

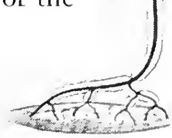


are disturbed, muscular cells contract. As we watch the hydra in the water, we can see the stimulation lead to movements of the tentacles and of the whole body, although we can see neither the nerve cells nor the motor cells.

Nerve Cells In man, as in all vertebrates, and in other species of complex animals, the nerve cells, or *neurons*, are clearly distinct from other kinds of cells. A neuron may be compared to a muscle cell as a unit of muscle, or to a gland cell as a unit of gland. Moreover, there are several kinds of nerve cells (see illustration in margins): (1) Neurons that receive impressions from the outside (for example, through the skin, the eye, etc.) we may call *receptors*, or receivers of stimuli. Since they transmit impulses *toward* the brain or spinal cord, these sensory neurons, or receptors, are also called *af*-ferent, that is, bearing toward. (2) Neurons that arouse muscles or glands into action are called *effectors* —effect-producing. Since effectors bear impulses away from the cord or brain, they are also called *ef*-ferent neurons. (3) Neurons that connect afferent and efferent neurons are called *associative* neurons, or simply *connectors*.

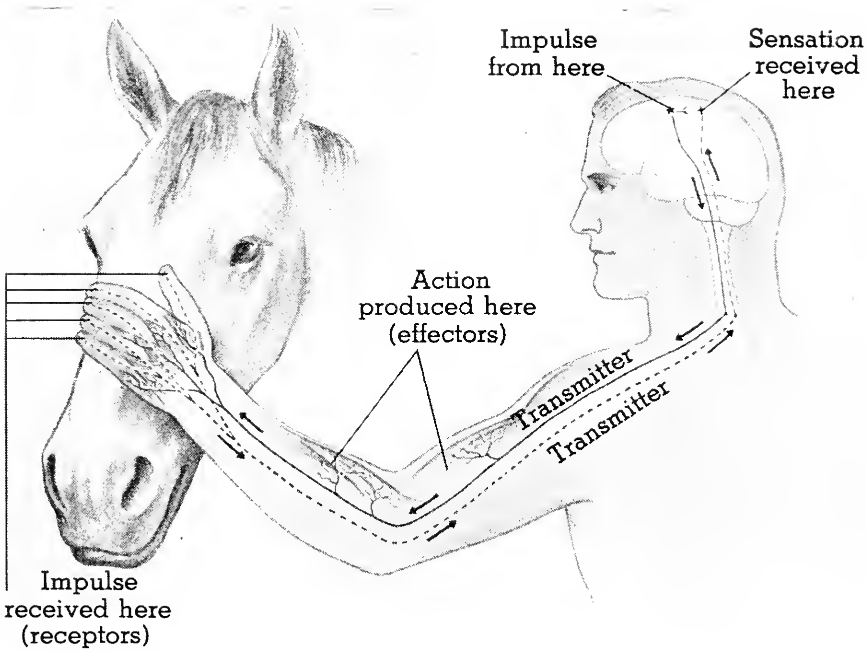
The whitish strands commonly called nerves reach to all parts of the body, and some of them are large enough for us to see without a microscope. Nerves consist of many fibers bound together by connective tissue and associated with blood-vessels and lymphatics. The cell bodies are grouped in the brain, in the core of the





TYPES OF NEURONS

A typical nerve cell has a nucleus and an extension, or axon, that ends in fine treelike branching, or dendrites. The endings are in close contact with dendrites of other cells, or with sensory structures, or with muscles or glands



FUNCTIONS OF NERVE CELLS

A living body senses outside events at the ends of "receiving" nerves, or receptors. Nerve impulses are transmitted by nerves toward central organs. The living body also produces "effects" upon the outside world, through special organs, such as muscles of the hands, called effectors

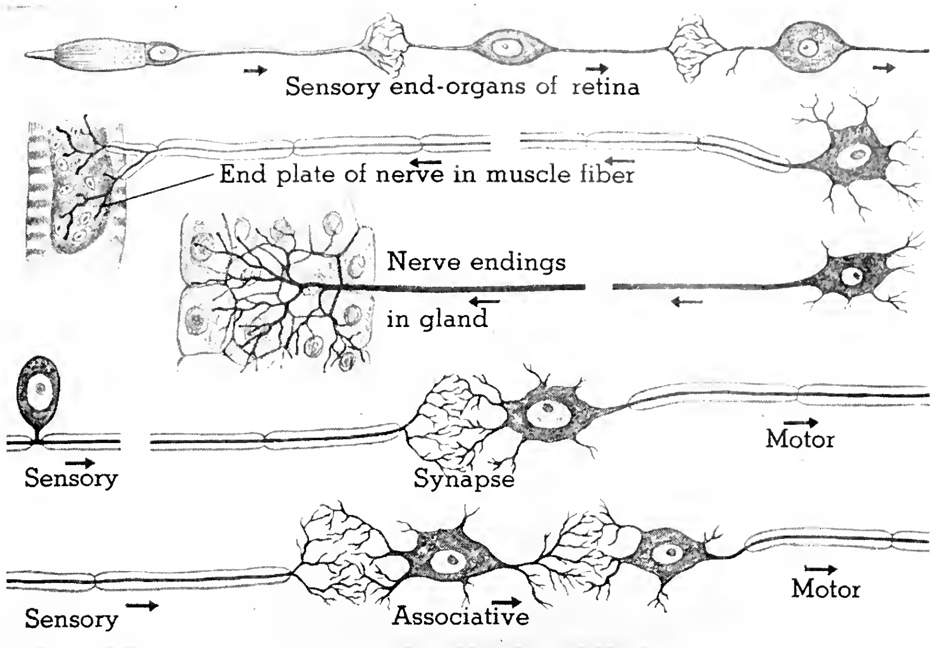
spinal cord, and in special clumps called *ganglia.* These masses of cell bodies make up the "gray matter" of the nervous system; the strands of fibers make up the "white matter".

There are also special neurons in the gray portions of the brain that are related to knowing, feeling, imagining, and the voluntary control of muscles (see illustration above).

The protoplasm of one nerve cell and the protoplasm of the next are connected through the branching ends of the *axons* and the *dendrites.* If the endings of a sensory, or afferent, neuron are stimulated, the disturbance passes through the cell body and the axon to the terminals, which are in contact with the dendrite of an associative cell. From this cell the impulse is transmitted to the dendrites of an efferent cell and on through the axon of this one to the terminals in some effector—for example, a muscle or a gland (see illustration, p. 275).

The Main Nerve Axis[1] Among the vertebrate animals, as among other bilaterally symmetrical animals, such as insects and segmented worms, a

[1]See Nos. 1 and 2, p. 298.

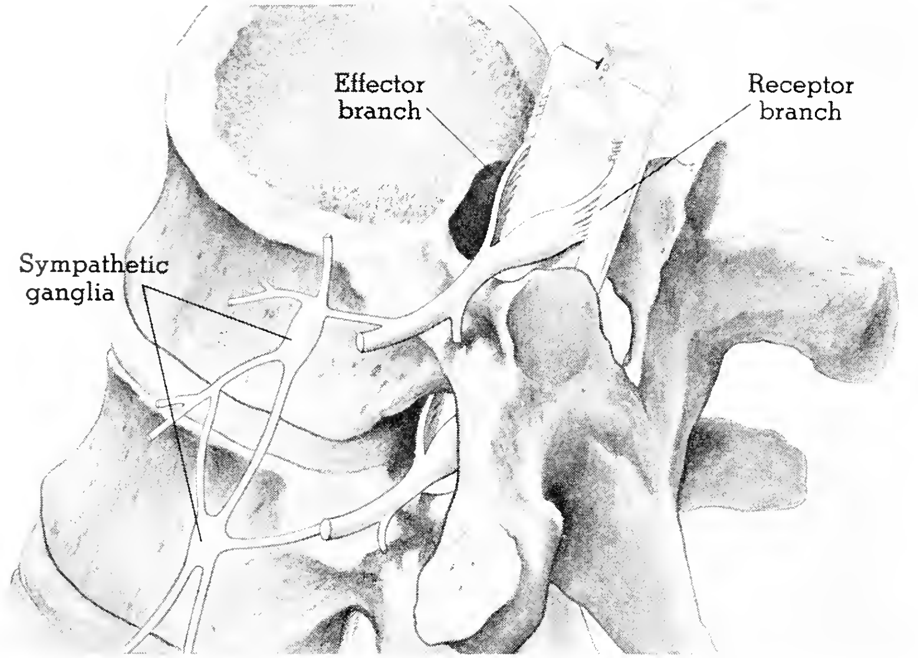


NERVE CONNECTIONS

Nerve cells are connected with sensory receptive organs (such as eyes or ears), with muscles or glands, and with other nerve cells. The end branchings of a nerve cell form intimate connections with the branchings of another nerve cell or with other tissue cells. Nerve impulses pass through a nerve cell in one direction only, although an electric current can be made to pass through a nerve cell in either direction

main nerve runs the length of the body. This has side branches which connect with the skin and special sense organs and also with muscles (see illustration above). These connections have been definitely traced in many kinds of animals, including man. Moreover, experiments show clearly that the parts of the structure behave in complete agreement with the idea of a "reflex" (see page 262). There is a definite nerve connection between the point of stimulation and the acting muscle. This path consists of at least two parts: (1) an afferent or incoming neuron, the sensory portion; and (2) an efferent or outgoing neuron, the motor portion. Most reflexes involve one or more intermediary associative neurons. The entire path makes up the *reflex arc* (see illustration, p. 282).

In all animals with a central nervous system the axis contains fibers that run, so to say, forward and backward, connecting ganglia in the various segments. Through these nerve connections stimuli acting upon receptors in one part of the body can produce effects in other segments, both in front of and behind the stimulated region.

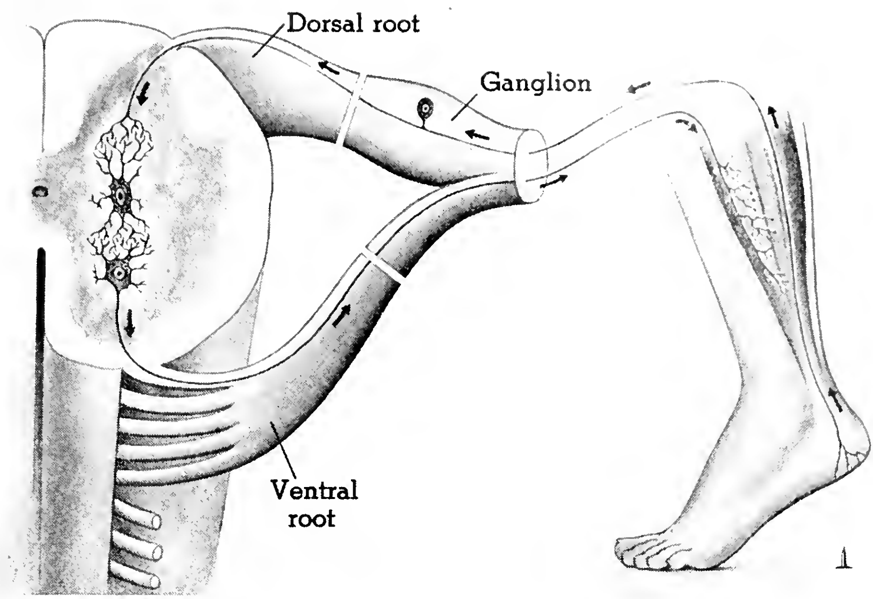


THE MAIN NERVE AXIS IN VERTEBRATES

Among bilaterally symmetrical animals there is a main nerve axis with side branches which lead to the skin and special sensory structures, and to muscles. Many stimuli and many reactions of the organism may be completed within a narrow sector of the body; but the cord carries vast numbers of connecting nerve fibers which relate all parts of the body to all the other parts

These neurons connecting different "levels" of the nervous system help us to understand some of the more complex movements that appear to be just as automatic as simple reflexes involving only the parts of a segment. Let us suppose that one smells a strange odor. If it produces any impression at all, one is likely to turn toward it—or away from it. In any case, the muscles used may include those of the neck and shoulders and even those of the trunk and legs.

The Brain In all vertebrate animals the front end of the central nervous system is enlarged into a mass of neurons, connective tissue and blood vessels, together constituting the brain (see illustration, p. 281). The average weight of the brain of adult males in western Europe is about 1400 grams; and of that of the females, about 100 grams less. Many human brains weigh from 1500 to 1800 grams. With two exceptions, man's is the largest brain among the inhabitants of the world. The true whale has a brain of 6700 grams; and the brain of the Indian elephant attains over 5400 grams. In relation to the size of the body, however, man's brain is much greater than

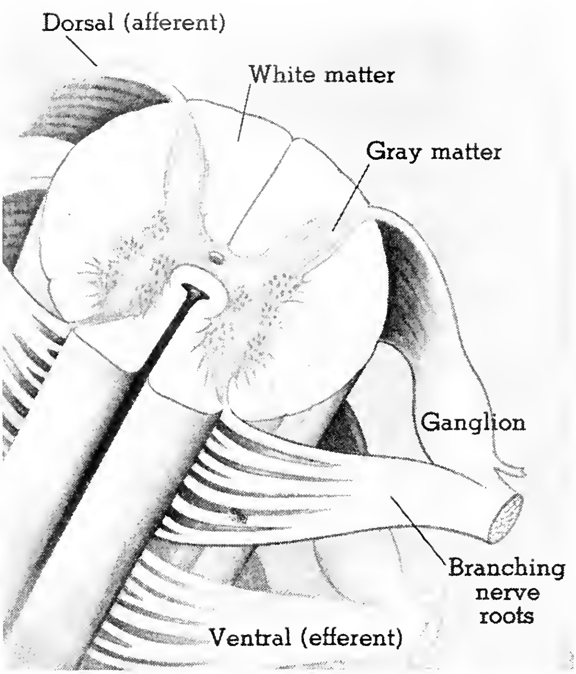


IN AND OUT NERVE PATHS

If the dorsal root of an intervertebral nerve is cut or broken, stimulating the end away from the spinal cord produces no effects; but stimulating the end connected with the cord arouses the same sensations as stimulating the corresponding sensory endings. That is, this branch transmits impulses only toward the brain. If the ventral branch of the nerve is cut or broken, stimulating the end near the cord produces no results; but stimulating the portion away from the cord arouses muscular contractions or glandular secretions, or both. That is, this branch transmits impulses only outward from the center

that of any of these animals. Thus the ratio of brain-weight to body-weight is 1:40–42 in man; 1:500 in the elephant; and 1:12,000 in the humpbacked whale. On the other hand, some of the smallest mammals have relatively larger brains: the ratio of brain-weight to body-weight is 1:22–26 in some of the marmosets and some fancy breeds of mice, and even more in some of the spider monkeys—about 1:17–20 (see table, p. 297).

The cortex, or "rind", of the cerebrum consists of nerve cells. In mammals this gray layer is very much wrinkled, so that there is relatively more surface than in lower vertebrates. The primates have more complex brains than other mammals. The cortex of the primates has five distinct layers of cells, as against three in other mammals. This fact is apparently related to the greater capacity of primates to learn; and in the case of man this means also the capacity to imagine, to form and to remember abstract ideas, to



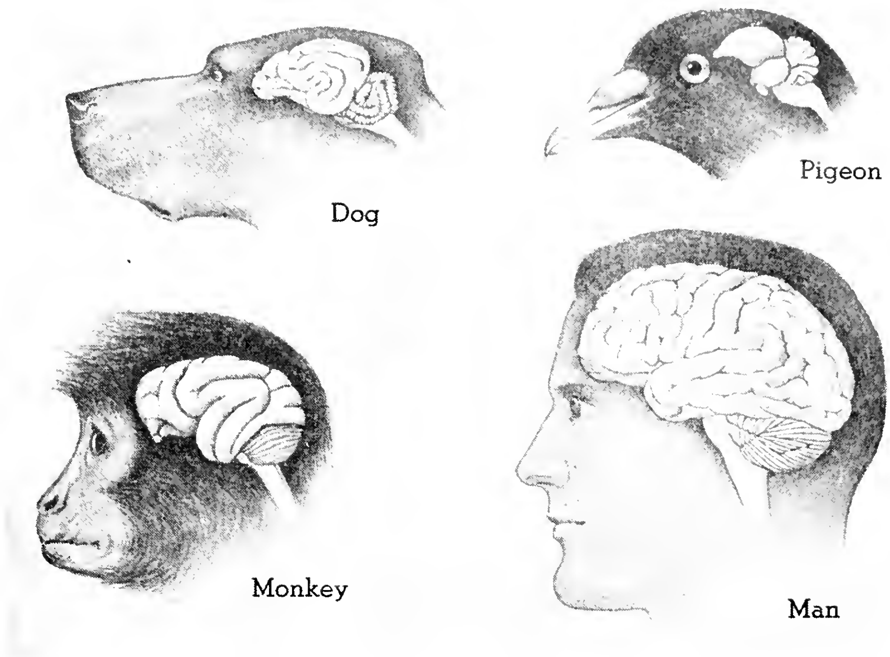
A cross section of the spinal cord shows a rather distinct gray pattern, somewhat like a butterfly in outline, within a whitish mass. The white part of the cord consists largely of axons, which transmit nervous impulses up and down — toward the brain and toward other segments of the body. The gray matter consists largely of cell bodies that act as switching centers, receiving impulses from afferent nerves and shunting them off into efferent nerves as reflexes or transmitting impulses from efferent as well as from afferent nerves, up and down the axis. Ganglia usually consist of cell bodies; the nerve strands consist of axons and supporting tissues

THE NERVE CONNECTIONS OF THE SPINAL CORD

plan, to think. Although man has neither the largest brain by absolute weight nor the largest in relation to the size of his body, his brain is probably the most efficient for bringing about changes in the world and for making adjustments to changes.

We have seen that an *awareness* is associated with some of the reflex actions. We interpret this fact by supposing that the receptor and the effector neurons of the reflex arc are connected also with the brain, by way of the spinal cord (see illustration, p. 282). Impulses to the cerebrum have to do with consciousness. Impulses from the cerebrum control voluntary action, but the cerebrum cannot control the reflexes, of which we are in most cases not aware.

Certain portions of the cerebral cortex appear to be connected with specific sensations or movements. The charting of these connections is based upon experimental studies with various mammals, and upon experiences with the diseased or injured brains of human beings (see illustration, p. 283). The matter is not so simple, however, as the diagram suggests, for the function of each region seems to be influenced by all the others. Every conscious desire, as well as every deliberate or purposeful action, seems to depend upon impulses starting from the gray matter in the brain or upon stimuli leading to the gray matter.



THE BRAINS OF VERTEBRATES

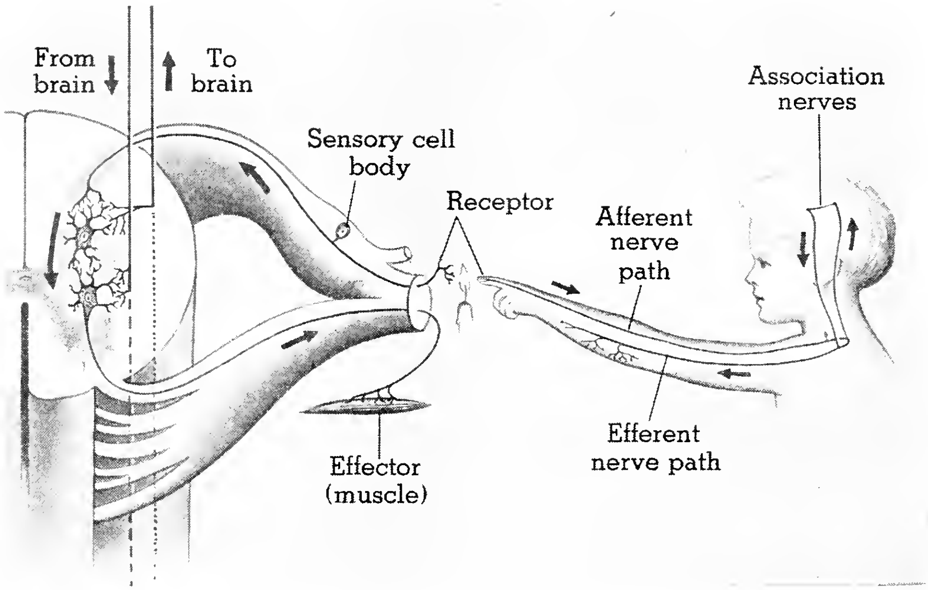
In birds the cerebellum is relatively larger than in mammals. In mammals there is an increase in the amount of convolution, or wrinkling, of the brain cortex—the "bark" of the cerebrum. The extent of the wrinkling is connected with the number of cells and the complexity of their connections

Living without a Brain[1] You have no doubt heard of someone running around like a hen with her head chopped off. A bird or frog can survive for days without using its brain. If the base of a frog's brain is cut through, the animal will still move a hind leg so as to brush away anything that touches the skin on that side. Many experiments show that animals can carry out rather complex movements involving many parts of the body when practically all the brain has been removed.

We explain such brainless activities by the fact that nerve paths to the effectors may be stimulated by processes outside the brain. These brainless animals still lack something of being fully "alive". They never start anything on their own initiative, not even taking food when it is placed right before them. They will swallow food placed in the mouth, digest food, and carry on other so-called "vital" functions. They will move away when pushed, but will not dodge a threat.

Such a brainless animal is indeed not strictly dead, but its living is largely

[1]See No. 3, p. 299.



THE BURNT HAND DRAWS BACK

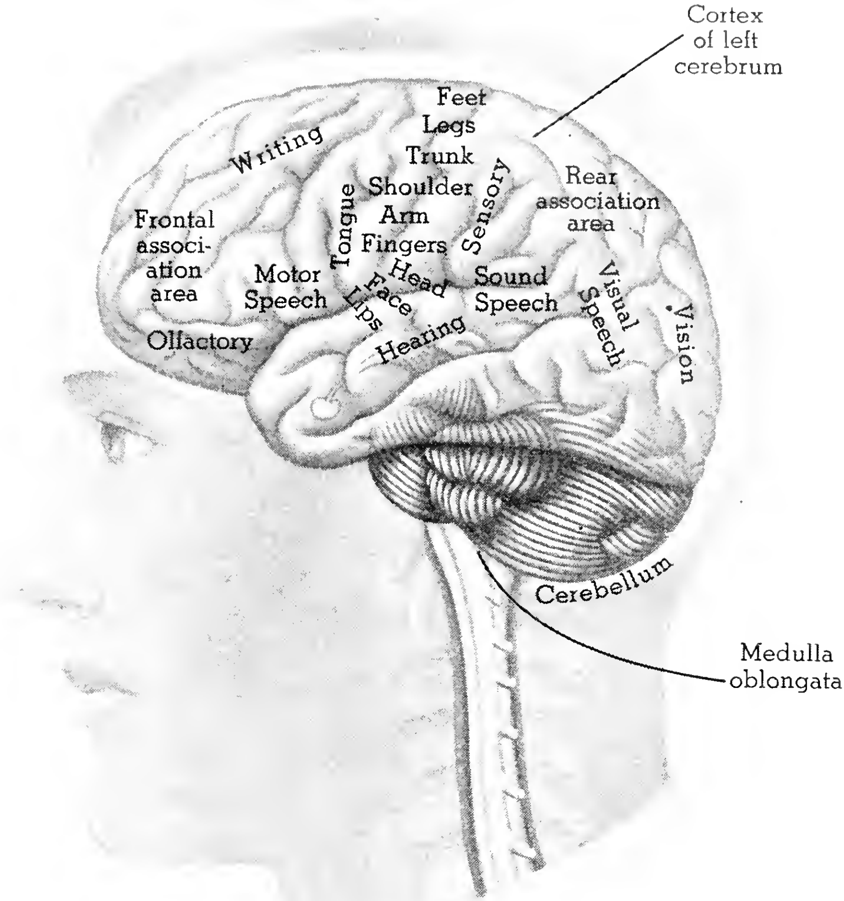
When nerve endings in the skin are disturbed, an impulse travels up the afferent, or sensory, nerve cell. The disturbance is discharged to an efferent, or motor, nerve cell. Some is discharged also to an associated cell and transmitted to the brain. The stimulus in the motor nerve cell arouses contraction of muscle. The path from the receptor to the spinal cord to the effector is called a reflex arc

vegetative. A person without a brain, or with one not working, is also largely vegetative, even if he sometimes uses his striped muscles vigorously.

The Brain and Reflexes[1] It is not difficult to show that animals—whether those with brains or those without—depend upon reflexes, or upon the reflex arcs in the nervous system. Let us suppose that a certain part of the *sciatic* nerve (the main nerve trunk running down the leg) were broken, destroying the continuity of the *afferent* fibers (see illustration, p. 284). One might then walk on carpet tacks or hot iron and not know it unless he happened to be watching his feet. Accordingly, one would not jump to avoid injury. Under these circumstances a person would still be able to move his legs or to jump if he *wanted* to. On the other hand, if the portion carrying *efferent* fibers were cut, one would remain just as sensitive as ever to carpet tacks or hot iron or tickling; but he could not move his legs, no matter how much he wanted to. And they certainly would not move of themselves, for the part of the reflex arc connecting the spinal cord with the muscles would be broken.

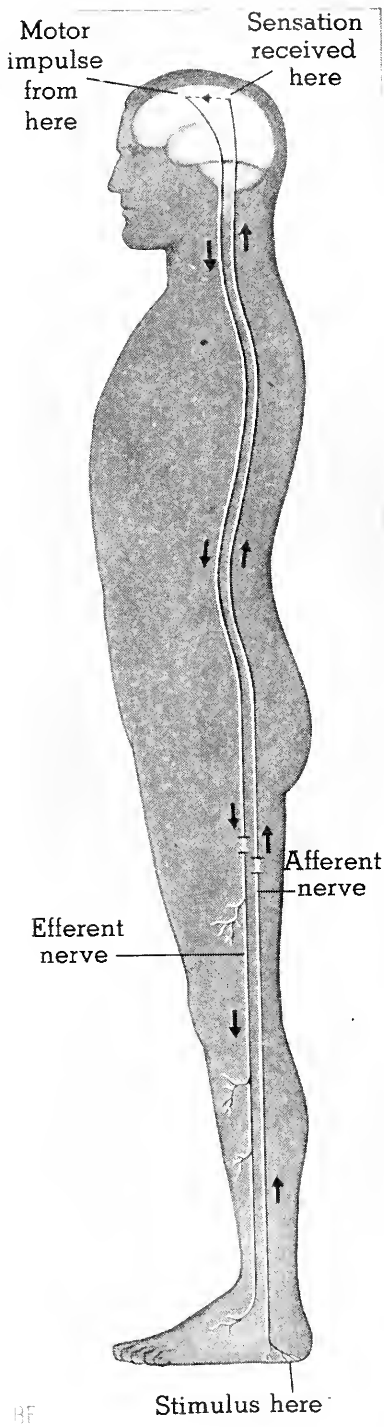
A large part of human activity may thus be seen to be mechanical, or

[1]See Nos. 4 and 5, p. 299.



LOCALIZATION OF FUNCTIONS IN THE CEREBRUM

Certain regions of the brain cortex seem to be related to receiving sensation from specific regions of the body, while other regions of the brain initiate movements of particular muscles. "Thinking" appears to be carried on by the association areas: the hind area has to do with knowing and understanding concrete facts and relations; the frontal area has to do with abstract thinking, self-control, concentration, and making decisions



automatic, as is much of the activity of other species. But while reflexes are inseparable from human conduct, they are not the distinctive characteristic of our behavior. For each reflex is a segment, or fraction, which we are able to study by itself. What we learn from these fragments does not necessarily tell us that the organism always acts as a whole. Or that the activity of the organism is always in relation to a complex situation, not merely a simple response to a single stimulus.

There are mechanical elements in human action, but life is more than the sum of these elements. Beyond these reflexes, there are high degrees of intelligence, high skills in adjustment, high levels of imagination, initiative and ingenuity. It is these that distinguish the animal with the modern brain from all other species.

How Do Nerves Receive Different Kinds of Stimuli?

General Sensitiveness and Special Sensitiveness[1] The naked protoplasm of various small plants and of the ameba and other protozoa seems to be equally sensitive to many different kinds of stimuli or disturbances. The protoplasm reacts to mechanical pressure or direct

BEHAVIOR LIMITED BY NERVE CONNECTIONS

If the afferent nerve of the arm or leg is cut, one might move the limb freely, but could not feel any stimuli that it might receive from the outside. He could walk so long as the efferent nerves were intact. If the efferent nerve were cut, he could feel pain or tickling in his hands or feet, but could not move a limb

[1]See Nos. 6, 7, and 8, pp. 299 and 300.

touch, to electrical disturbance, and to chemical action. Changes in temperature and light also stimulate protoplasm. In the more complex types of animals, however, most of the protoplasm is inside the body and protected against contact with happenings outside. Such animals receive stimuli through special organs, just as they act upon their environments through special effectors—hands and feet, for example, or jaws and teeth.

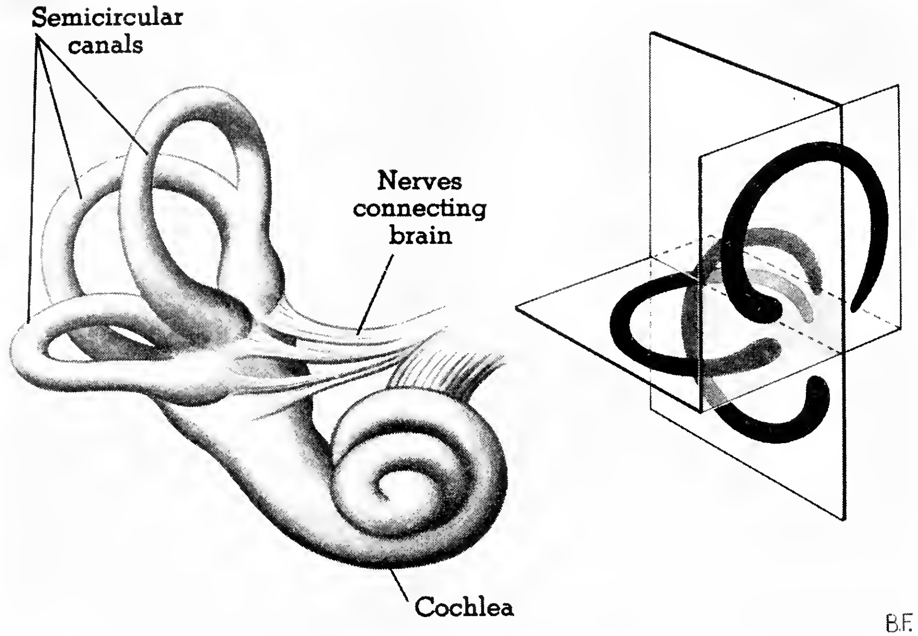
Thousands of nerve endings in our skin are sensitive to slight pressure or contact (see illustration, p. 217). The touch receptors are more closely crowded in the tips of the fingers and on the tongue than in other regions. There are also special end-organs sensitive to heat and others sensitive to cold. The stimulation is carried along through one or more neurons until it finally sets up a disturbance in one or more cells of the brain cortex. Here the stimulus is at last translated into a feeling, or sensation. We say that the finger is hot, but it is in the brain that we *feel* the stimulus. The elevator operator looks at the indicator and says, "Somebody rang on the tenth floor". A button was pushed on the tenth floor, but he *heard* the bell wherever he happened to be at the time, and he "knew" that the signal came from the tenth floor because the indicator said "10" to him.

Inside the organism, mechanical pressures or contacts may also act as stimuli—the pressure of food in the intestine, for example, or the presence of urine in the bladder. Some of these touch or pressure stimuli start reflexes; others bring impulses to the cortex and make us aware of the condition or the position of the body.

If you lie quietly with your eyes closed, you are still able to tell the position of your body and of your limbs, because of nerve-endings which are stimulated at the points in contact with the supporting surface. The varying tensions of the muscles attached to the bones of the skeleton give you a feel of the relative position of the trunk and limbs. As you turn about, changing strains of the floating viscera and variations in pressure on parts that are not rigid contribute to the same feeling of position in space, or of movement. In the inner ear is a special organ that seems to be directly related to the sensation of position-of-the-body and to sensations of spinning and turning, which sometimes lead to dizziness (see illustration, p. 286).

Our balancing organs are highly specialized *contact* receptors, which, however, we do not ordinarily appreciate as we do our other sense organs. In the swollen region near the end of each ear canal sensitive hairs project into the liquid. When the head starts moving or turning, the liquid lags behind somewhat, bending the hairs in the opposite direction. One "senses" the changed position at this point. As the fluid's movement catches up with that of the canal, the hairs become erect (see illustration, p. 287).

In many crustaceans and molluscs there is a balancing organ, or statocyst, which consists essentially of a hollow space with sensitive walls that con-

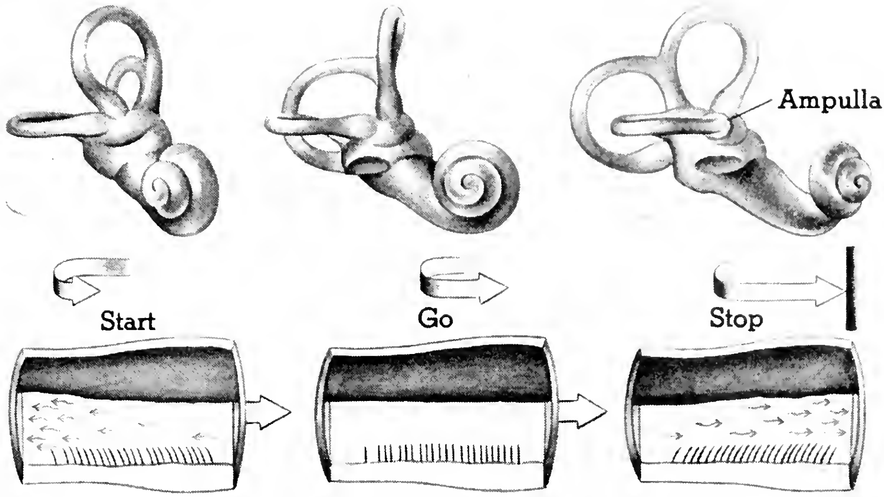


BALANCING ORGAN IN MAN

In vertebrates the balancing organ consists essentially of three hollow rings lined with sensitive nerve endings. These three rings correspond to the three planes of the space in which we move about. We do not ordinarily "feel" the balance, but in skating, dancing, flying, tightrope walking, in all physical activities that involve rapid changes in the body's position, the co-ordination of movements depends largely on these canals

tains some floating grains of sand (see illustration, p. 288). An experimenter removed the sand from several crayfish and replaced it with iron particles. This did not affect the movements of the crayfish; but when he brought a magnet near one of these animals, it behaved as if the side toward the magnet were *down*. This experiment shows that the statocyst works through the displacement of the solid particles in the course of the animal's movements. It also shows the automatic character of some of the animal's adjustments.

Hearing When we hear the low roar of the airplane engine becoming steadily louder, it does not occur to us that we are *touched* by anything. We think of the sound as coming from a great distance, as we think of the airplane itself going a great distance. Yet we may reasonably think of our hearing organs as highly specialized touch receptors. For according to the studies of physicists, sensations of sound correspond to vibrations in the air—actual air movements striking upon our eardrums much as waves of the



Section of ampulla in motion

HOW OUR BALANCING ORGAN WORKS

In the rapid movement of a plane, every turn, bank, climb, or dive involves the centrifugal effects upon the semicircular canals. As a result, the pilot is frequently confused and unable to judge his position or direction except by means of special instruments. In steady movement the hairs and the fluid in the canals move together and there is no sensation. In a quick start or turn or stop, the fluid in the canals holds back or runs ahead and so bends the sensitive hairs

sea strike against a floating buoy, setting it in motion. In other air-breathing vertebrates the hearing organ is very much like our own (see illustration, p. 289). The stretched membrane, or drum, is the receiving area for sound vibrations in many different types of animals. In some insects and spiders, however, the sound waves are received by fine, stretched hairs connected with nerve fibers or by fine hairs standing out on the antennae.

Animals differ very much as to the range of sound vibrations they can perceive. Some animals are quite insensitive to sounds that nearly all human beings can hear, while some insects can perceive a much higher pitch than any human being. The human ear discovers sounds of various pitch when the vibrations of the air are at least 16 to 20 per second but not more than 25,000 to 40,000 per second. In the middle register, which includes the range of the human voice and most familiar sounds, we can distinguish very slight differences in pitch. A trained ear can distinguish more than 1000 shades of pitch in one octave.

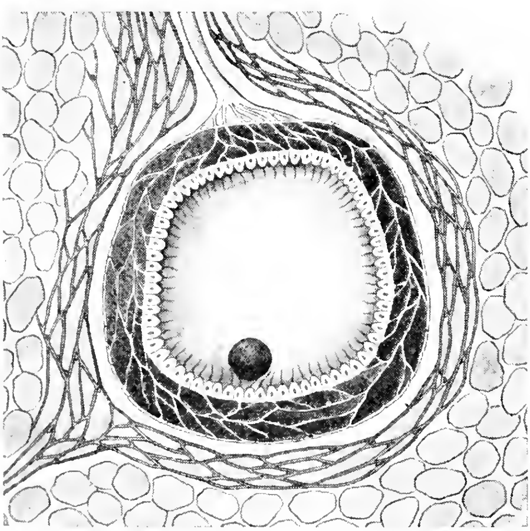
Chemical Sensitiveness Protozoa are attracted by the presence of various kinds of bacteria, but they are repelled by various chemical substances.

They will swallow the bacteria and pass sand grains by. Our white corpuscles react to various kinds of bacteria much as the ameba reacts to chemical stimuli (see page 188). In the retina of the eye light brings about chemical changes, just as it does in chlorophyl or in a photographic film. But in the retina, the chemical action sets up nerve stimulations.

The tip of the tongue is more sensitive to touch than are the tips of the fingers. Yet we think of the tongue not as a touching organ, but as a tasting one—that is, an organ sensitive to chemical stimulations. Touch and taste are related, however, since chemical action takes place only when two substances come in contact. Another related sense is that by which we distinguish odors. In both tasting and smelling, stimulation depends upon the presence of particular substances in direct contact with the nerve-endings. These materials dissolve in water and diffuse directly into the sensitive cells.

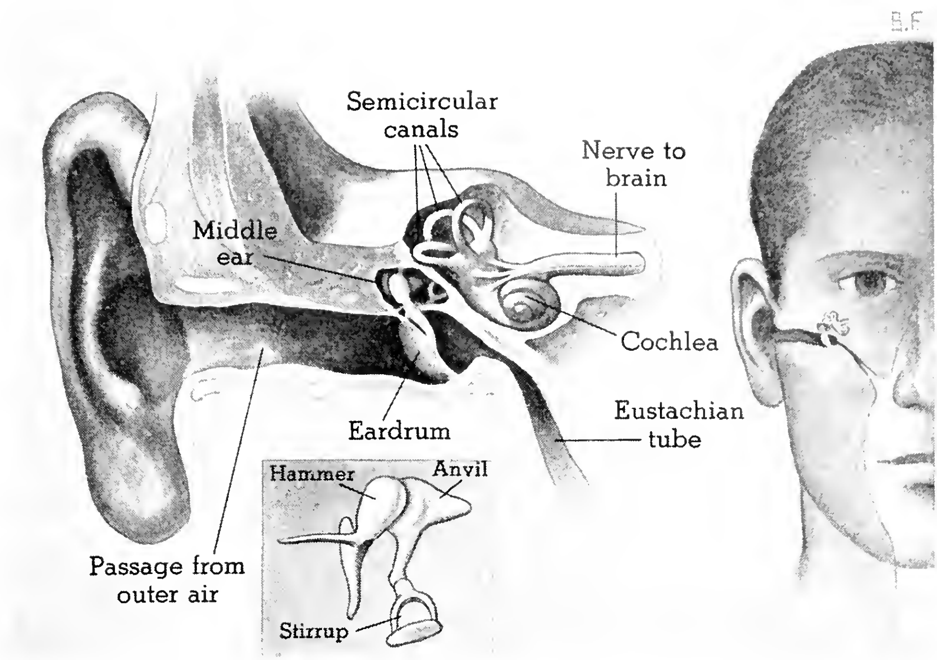
The special receptors of taste are very small projections on the upper surface of the tongue and in other parts of the mouth lining and of the pharynx. These contain nerve endings connected with the brain cells, through which we are made aware of taste. Our taste system can distinguish four classes of tastes: *sweet*, *sour*, *salt*, and *bitter*.

The lining of the nose is sensitive to touch, as well as to odor. The sneeze reflex is started by either a strong odor stimulation or by a touch on some of the nerve endings in the nostrils. The sense of odor, in which the chemical stimulant touches the surfaces in a volatile state, is much more acute in many insects and lower mammals than it is in man.



The little "stone" in the cavity of the statocyst rolls about freely as the body changes its position. As it moves about in this way, it comes in contact with delicate hairs that line the cavity, now touching one group, now another. These hairs are outgrowths of sensitive cells which connect with nerve cells. These nerve cells in turn are connected with muscles, forming reflex arcs. As different parts of the lining are stimulated, different skeletal muscles are made to contract. In this way the animal retains or recovers its position in relation to the horizontal

BALANCING ORGAN IN A SNAIL



THE HUMAN EAR

A sound vibration of the air strikes the tympanum, or drum, and is transmitted through a chain of tiny bones to the liquid filling the "labyrinth". Disturbances of the liquid stimulate delicate nerve endings in the cochlea, and the nervous impulses are transmitted to special regions of the brain

We can see the relationship between these two chemical senses and to an organism's adjustments in various ways. Thus both pleasant food odors and food tastes arouse the salivary reflexes. A blindfolded person, holding his nose to prevent currents of air from passing through it, cannot distinguish ground coffee, for example, from sawdust, or vanilla flavor from raspberry. When we speak of the taste of good food, we usually mean the odor. Feelings of nausea and the act of vomiting may be started by disagreeable odors.

Sensitiveness to Light We value seeing perhaps more than our other senses because it puts us "in touch" with more of the world—with much of the world that we are, in fact, unable to touch directly. We are able, however, to understand that seeing depends upon chemical changes in the sensitive structures—in the pigments that characterize all light-sensitive organs. The source of the light, the objects that reflect the light by which we see, may be very far away. The action on the nerve-endings, however, is very close by, just as close as in the case of odor and taste or as in the case of an actual push!

All branches of the plant world and all branches of the animal world are sensitive to light. But only three main groups of animals can actually *see.* These are the highest mollusks, the arthropods, and the vertebrates.

By *seeing* we mean not simply discriminating between light and dark, but distinguishing forms at some distance. The starfish, for example, has light-sensitive spots at the ends of the rays, but these are not true eyes (see illustration, p. 230). Comparatively few of the mollusks have special light organs. In most of the bivalves the edge of the mantle is vaguely sensitive to light. The scallops have "eyespots" at the edge of the mantle, but in the snails, the squids, and the octopuses there are definite eyes. The eye of the octopus resembles that of the backboned animals in many ways.

Vertebrate Eyes Among all backboned animals the eyes are very much alike (see illustration opposite). Important differences correspond to the habits and the habitats of the different groups. Animals living in the water, for example, have a different kind of lens. Animals that prowl about at night have a different kind of pupil. The eye is moved about in its setting by muscles attached to the bony framework, and is further protected by the movable lids and watery secretions.

The fishes (except the sharks) lack eyelids. The eyelids of snakes are permanently closed, but transparent. Among the birds and in many reptiles there is a single eyelid that passes over the eyeball from the inner corner, under the outer pair of eyelids.

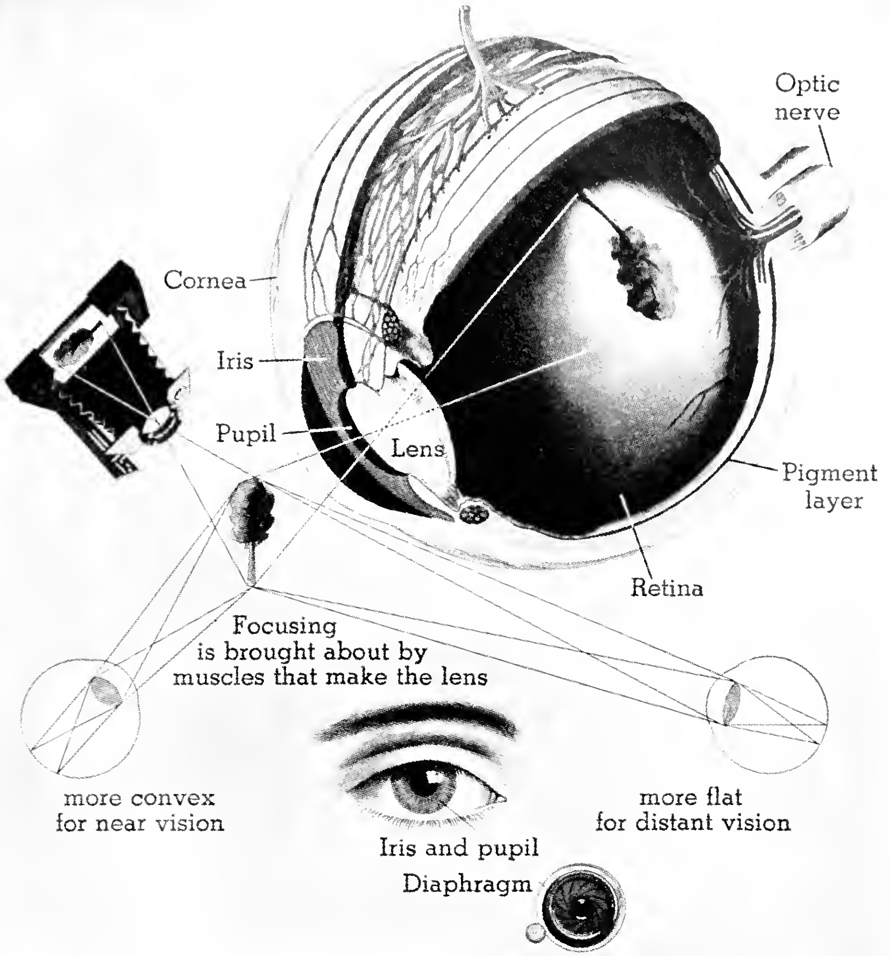
Compound Eyes Insects and other arthropods commonly have *compound eyes,* and many of them have also simple eyes. In each of the eyes there are many nerve-cell endings. The lens projects upon these sensitive points a tiny patchwork of varying lights and shadows. Thus each of the many eyes forms some tiny picture of a portion of the outside world.

A compound eye of an insect or lobster may have from twenty to several thousand separate facets. The impressions produced in the units of a compound eye are probably not very distinct. But as the animal gets a mosaic of many simultaneous views from somewhat different angles, it is disturbed by very slight movements. Most insects are able to detect movements in practically all directions, though not at a very great distance.

The Senses and Adjustment[1] Most of the organs through which we receive stimuli from the outer world depend upon direct contact between the body and some object. Reaction to such stimuli is ordinarily immediate —of a reflex character. If an animal is to profit from its ability to sense such stimuli, it must respond promptly. And if the stimulus comes from possible food, the reaction must take place before the food has time to get away.

The three senses that enable an organism to receive stimuli from objects

[1]See No. 9, p. 300.



THE VERTEBRATE EYE

The eye, like the camera, has a lens at one end and a sensitive surface at the other end. In front of the lens a diaphragm regulates the amount of light admitted. In the eye the sensitive surface (retina) is backed by a layer of pigment and connected with the optic nerve

at some distance—sight, hearing, and smell—give opportunity to discover food or enemies while there is still a little time before action is imperative. Accordingly, these senses act in many situations without bringing about an immediate reaction. Now, as we have already observed, a stimulus may lead to an immediate reflex, but the reflex seldom exists by itself. On the one hand, the stimulus may start impulses that are transmitted to higher levels of the nervous system, as well as to the usual effectors. On the other

hand, a stimulus seldom acts upon the body apart from all other stimuli, so that the normal reaction to one stimulus may interfere with the normal reaction to one or more other stimuli. A dog about to seize a piece of meat which he spies might be stopped in his tracks by a simultaneous loud sound.

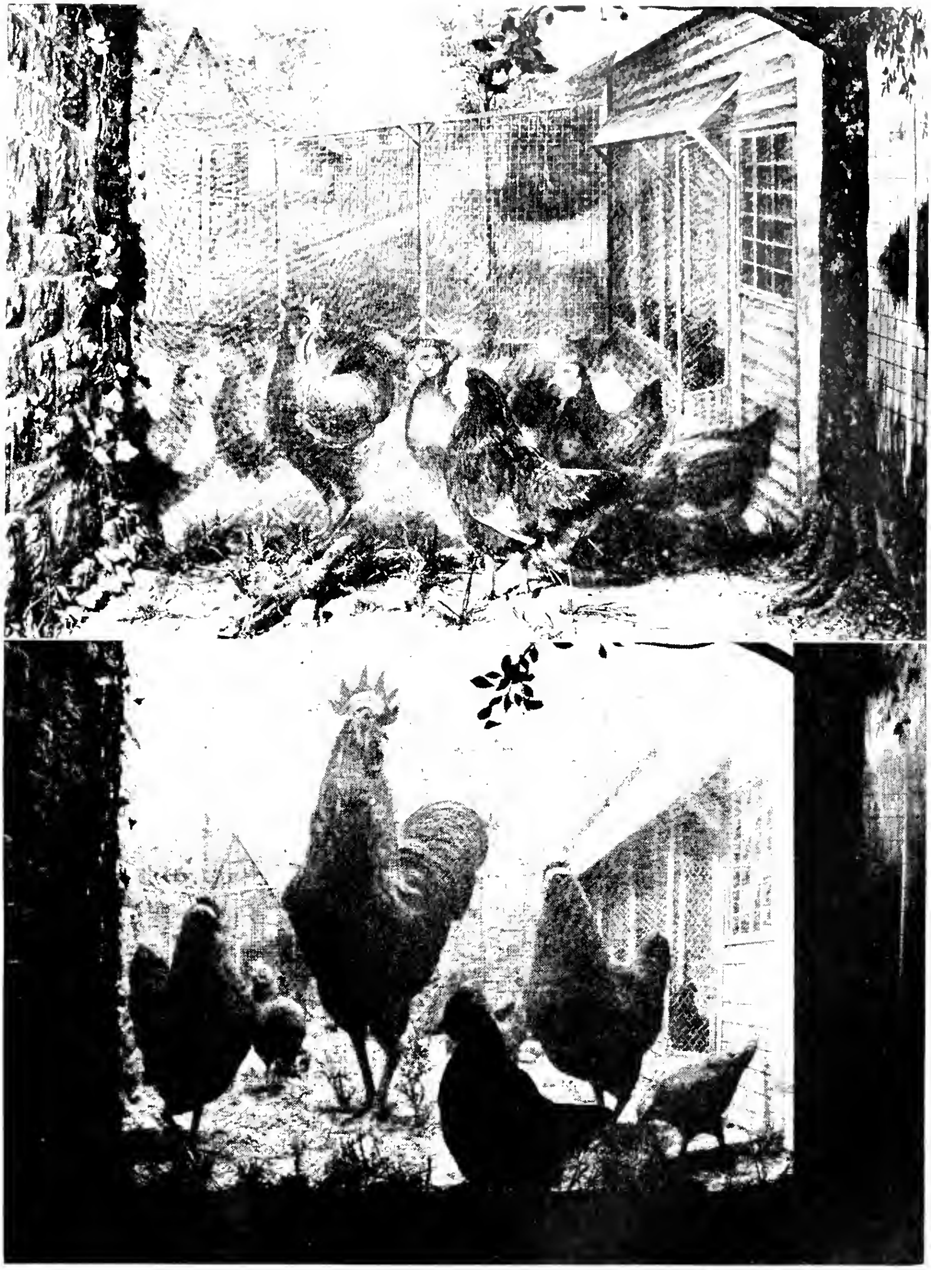
The impressions which an organism receives through various stimuli that do not immediately set up the normal reflex seem to register somehow in the brain cells. In this way some of the experiences influence the animal's *later* activities. It is in some such way that we are capable of *learning from experience*; the delayed or obstructed reaction gives the organism an opportunity to react in one of several ways, and the way "selected" seems to depend upon previous experience. It is probably in the delayed reaction that the organism makes a beginning at *control*—control of its own actions, and so in the end control of its environment.

How Do the Nerves Make the Other Organs Work?

Nerve Impulse If an efferent nerve that is connected with a gland is detached and applied to a muscle, it can act in its new position to stimulate the muscle. This kind of transposition has been repeatedly carried out in experiments. The results show that the nerve in such cases acts merely as a transmitter of energy or of a stimulus. The nerve apparently has no influence upon the character of the response. An electrical disturbance applied to a motor nerve brings about contraction of the muscle. A mechanical stimulus, such as that in the statocyst of a lobster (see page 285), brings about movements corresponding to the position of the movable sand grains—that is, to the particular nerve endings that are being stimulated.

How does disturbance at one end of a neuron bring about a change at the further end, sometimes many inches away? The transmission is accompanied by chemical and electrical changes. Perhaps it is a chemical disturbance which passes from point to point through the length of the neuron. Or the transmission may be a simple electrical impulse, such as passes through a wire. But apparently it is neither of these. Nor is it like the transmission of a shove through a billiard cue. Nerve transmission seems to be peculiar to protoplasm. And changes in the protoplasm itself take place in the process.

Voluntary and Involuntary Muscles In the simplest animals the whole protoplasm takes part in receiving a stimulus and in reacting to it. In our bodies, movements are brought about by the contraction of muscles, which make up the "flesh" in all larger animals (see illustration, p. 296). Through the striated skeletal muscles the animal moves about, grasps, gets and chews



American Museum of Natural History

HOW WE AND THE HEN SEE THE SAME WORLD

The hen's eye is not only nearer the ground than ours, but the curvature of its lens is different. Her retina probably differs from ours in its sensitiveness to colors. And certainly what she sees in this same world means one thing to her and something else to us

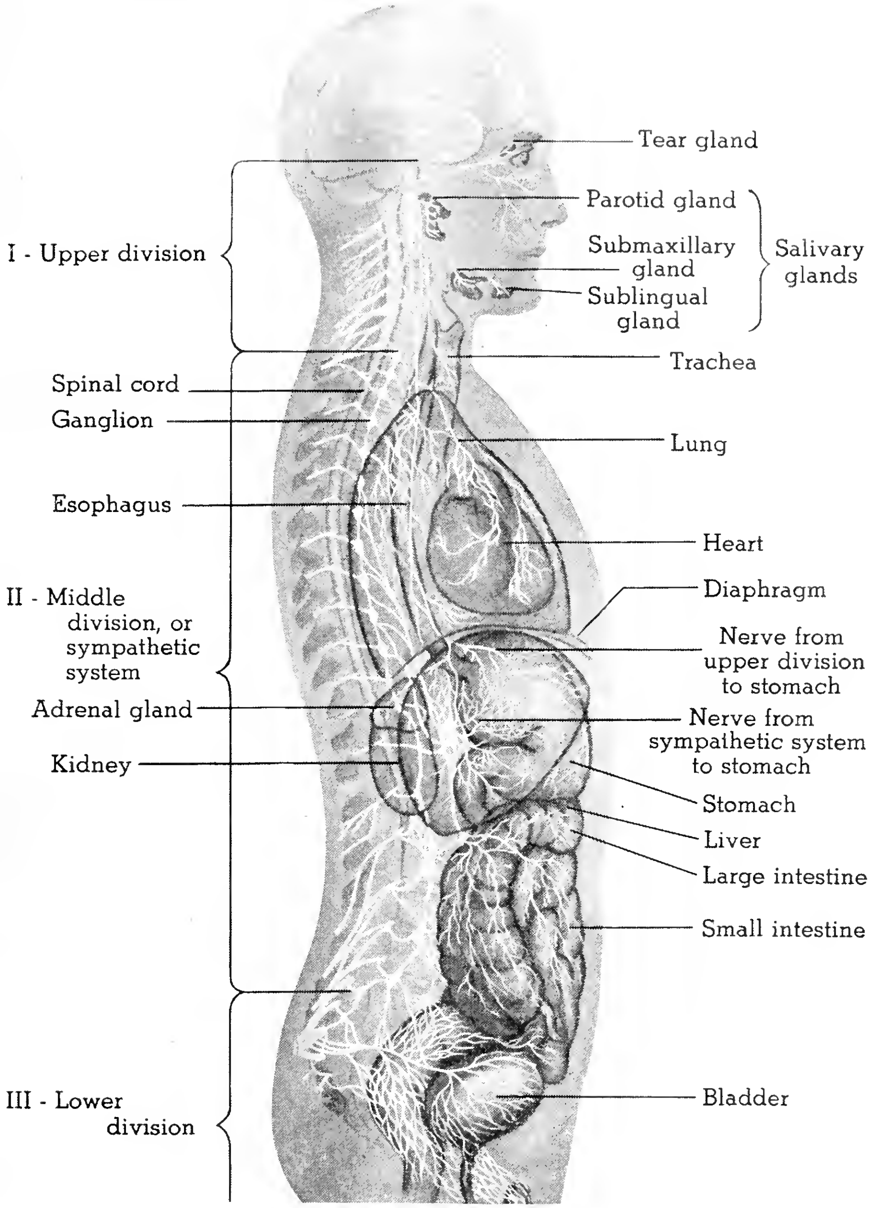
food, moves the eyes and ears, and makes sounds with the lungs and larynx. These muscles are called *voluntary*, being under more or less direct control of the central nervous system—the brain and spinal cord; or they contract in response to stimuli received by the sense organs. The heart muscles, however, are striped, but are not controlled voluntarily.

The smooth muscles relate the parts of the body to one another. Their contractions work the stomach wall, move the food along in the digestive tube, and control the diameters of the blood vessels. These *involuntary* muscles make up a system that works constantly, even while we are asleep. Life may go on indefinitely if most of the skeletal muscles are paralyzed, but if the smooth muscles are paralyzed, death comes quickly.

Infantile paralysis is a communicable disease, apparently caused by a virus. It is often fatal, but where victims recover they are usually crippled for life. No cure has been found for this disease. However, Elizabeth Kenny, an Australian nurse, found a way to *prevent the paralysis* in those who recover. In 1910 she had four sick children on her hands in a village far from hospitals and physicians, and she set to work with them, doing the best she could. The children recovered and she saved them all from becoming crippled. She had noticed that in the acute and most painful stage of the disease the skeletal muscles are in a state of continuous contraction or spasm. She helped the children to relax these muscles by means of hot applications. Then she helped the blood circulation move through the muscles by massaging them and by moving the limbs. Later she got the children to try to move the parts themselves, until they gradually acquired control over their muscles. Her method has been recognized by physicians to be sound and practical; and she has been training hundreds of nurses and technicians to use the method for preventing those who are attacked by the disease from remaining crippled.

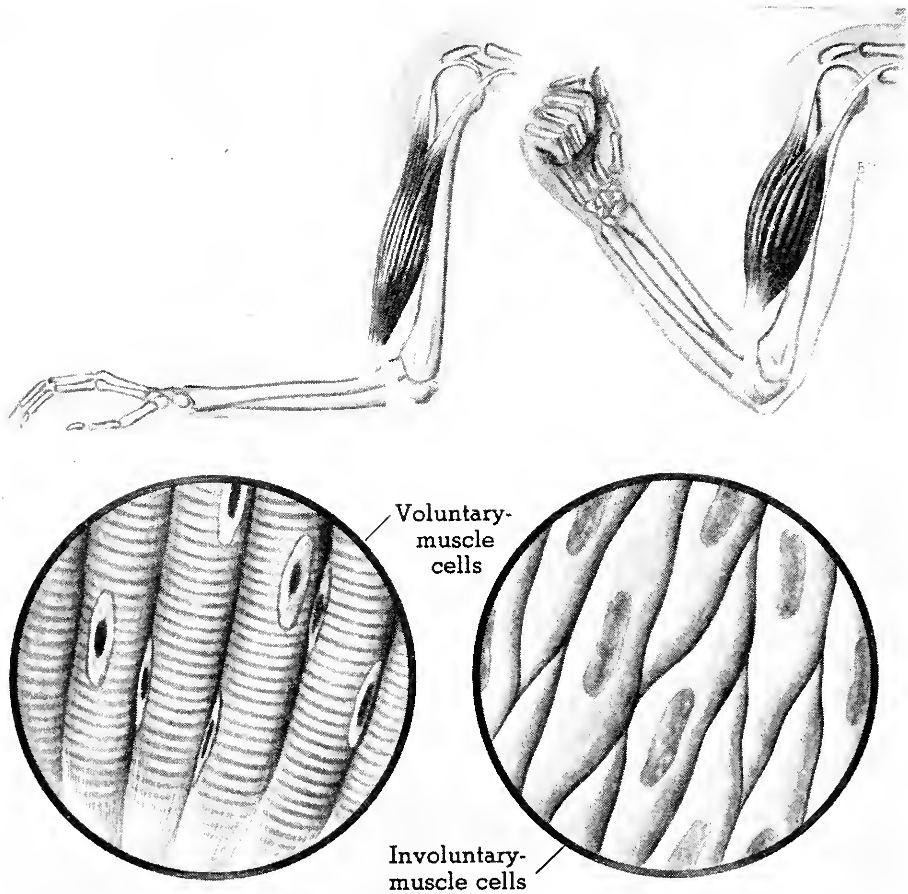
Our Double Nervous System Corresponding to the two sets of muscles, we have two sets of nerves: (1) The spinal cord and the brain, with their connections with the receptors and effectors, regulate the adjustment of the organism to its surroundings. (2) The *autonomic*, or self-regulating, system connects the internal organs with one another (see illustration, p. 295). It has no central organ. It consists of a double series of ganglia, or nerve-cell clusters, located in front of the spinal column (see illustration, p. 278).

We have already seen that as the activities of the brain and of the muscles vary, there is an automatic regulation of the heart, of breathing, of the blood-vessels, and of various glands. Some of these adjustments seem to result directly from an alteration of the processes in a remote part by chemical substances in the blood. When you increase muscular activity, for example, oxidation in the tissues is increased, and more carbon dioxide is



THE AUTONOMIC NERVOUS SYSTEM

A double chain of ganglia in front of the vertebral column connects the vegetative, or co-ordinating, system into a well-knit whole. These ganglia are connected not only with each other, but also with the circulatory, digestive, excretory, and reproductive organs, the glands, and the spinal nerves as well. Thus the unconscious and involuntary processes are tied up with the conscious and voluntary ones



VOLUNTARY AND INVOLUNTARY MUSCLES

Muscles attached to the bones and skin consist of cells that appear to be striped when seen with a microscope. They are connected with the brain or the spinal cord and are subject to voluntary control. Muscles of the blood vessels and the viscera are not striped; they are all involuntary muscles

discharged into the blood. Now the chemical condition of the blood directly stimulates the *vagus* nerve, which in turn acts upon the heart and the breathing. The adjustment of the pulse rate and breathing rate to changing conditions of the blood is thus almost immediate.

Because of its many connections with all the organs of the body, the autonomic nervous system ties all the parts together so that they act as a whole through the reflexes. The autonomic system includes in its control, however, much more than involuntary muscles. Some of the endocrine secretions (see page 313) act upon the autonomic nervous system; this in turn acts upon some of the endocrine glands.

Size of Brain (Brain-weight in Grams)

Various primates	
Gorilla	600
Chimpanzee	365–400
Gibbon	95–130
Earlier forms of man	
Pithecanthropus	900
Piltdown man	1300
Neanderthal	1400
Cro-Magnon	1550
Modern man	1400–2000
Various groups of peoples	950–1500
"One hundred eminent scholars", average weight	1478

In Brief

In all the higher animals specialized organs and tissues carry on in an exaggerated degree some special function that is common to all protoplasm.

Specialized structures are co-ordinated by the activities of sensitive cells called *neurons*, elaborated in vertebrates into the central brain-spine system, which connects with all parts of the body.

In all the members of a species the same reflexes occur in practically the same way. A *reflex arc* is the nerve path consisting of afferent and efferent neurons, with associative neurons.

Neurons of the central nervous system, that is, those related to knowing, feeling, and voluntary control, are classified according to their functions into (1) afferent nerves, which conduct impulses inward or toward the central portions; (2) efferent nerves, which bear impulses only outward, usually to muscles or to glands; (3) associated neurons, which act as intermediary, or bridging, paths.

Nerve-endings throughout the body, as well as on the surface, act as receptors for stimuli. Even a simple stimulus frequently sets going a whole group of reactions.

Many of the so-called "instincts" observed in animals are either reflexes or chains of reflexes. Most of the chains of responses which organisms make appear to be well suited to the situation from which they receive the stimulus.

Through specialized sense organs animals are sensitive to several varieties of stimuli. Species vary in the range of sensitiveness to different stimuli.

Movements in our bodies are brought about by the action of muscles: striated muscles are subject to voluntary control, smooth muscles are not.

The spinal cord and the brain, connected with the receptors and effectors, regulate the adjustment of an organism to its environment; the autonomic, or self-regulating system, ties all the parts together so that they act as a whole through the many reflexes.

The size and complexity of the brain are related to the ability of an organism to learn, to form associations between past experience and future conduct.

Certain portions of the cerebral cortex are supposed to be involved in specific sensations or movements.

Man lives under the greatest variety of conditions, probably because he is the most flexible in adjusting his natural responses and the most tenacious in accumulating experiences.

EXPLORATIONS AND PROJECTS

1 To study reflex responses in a vertebrate, stimulate a frog gently in various ways and note what responses the animal consistently makes to particular stimuli.

To find what responses the frog makes to touch, tickle the nostril, touch the eye, scratch the back gently, and stroke the back with thumb and forefinger. Enumerate as many simple and consistent responses as may be observed for each stimulus.

To find the responses of the frog to chemical stimuli, use weak ammonia: a matchstick moistened in ammonia. Bring it near the nostril; also touch it to the frog's back. Repeat each test several times to be sure that the movements are not random or accidental. (Wash the frog under running water after each application.)

To find the responses of the frog to electrical stimulation, use a two-point electrical terminal connected with a 6-volt battery[1] and touch the frog in several places. Note the consistent responses.

Compare the frog's responses to contact, to chemical stimulation, and to electrical stimulation.

2 To observe reflexes in human beings:

To observe the knee jerk, have subject sit erect with the legs crossed, so that the upper leg hangs limp from the knee; tap sharply just below the kneecap and observe the movement that results. Note whether this movement can be controlled.

To observe the wink responses, have someone make a sudden motion toward the subject, as if to strike the eye, and note reaction. To what extent can this reaction be controlled?

To observe the iris reflex, work in pairs: have the subject face the source of

[1]Fasten the ends of two wires to the end of a glass rod by means of adhesive or friction tape so that they project about a quarter of an inch and are held about a quarter of an inch apart.

light, with observer facing subject. Shade one eye with the hand for a minute, then quickly remove it while observing any changes in the iris. To what extent can iris movements be controlled by the subject?

To observe the automatic focusing, or fixation, response, have subject and observer face each other. Subject holds a pencil vertically at arm's length and fixes his eyes upon it while slowly bringing it toward his face until it is too close to be comfortable. How do the subject's eyes behave? What is there to show whether this is a native or a learned reaction?

3 To find whether the brain takes part in the reflexes of an animal, use a pithed frog and repeat the stimulations in No. 1 above.[1]

4 To observe chains of reflexes, or "habits", watch individuals performing familiar and repeated acts to see how closely the succession of movements is duplicated at different times.

Observe such sequences as using table utensils, cutting food, handling napkin, and so on; dressing and undressing—the order and manner in which the various garments are taken off and put on, and how they are laid down; and smoking—the sequence of acts that a habitual smoker follows.

Have several classmates remove their coats and lay them on their seats; then have each put his coat on again. Repeat this operation two or three times, and note, first, the different ways in which individuals may be doing what is "the same thing", and then the consistency with which each one follows his own pattern.

5 To determine reaction time, we may use a series of repeated acts, since it is difficult to measure the fraction of a second involved in most reactions. With one individual keeping time, have the other members of the group form a circle, each member facing the back of the person in front of him; the stimulus is a slap on the back, and the response is a slapping of the back of the person next in front. All will be alert to transmit the stimulus as quickly as possible, but will not anticipate by watching. Repeat the series several times; average the time around and average the time per individual.

6 To see whether vision is involved in ordinary body equilibrium, compare ability to stand still on one leg, without swaying, with eyes open and then with eyes closed.

7 To find variations in the skin's sensitiveness to touch, explore different parts of the skin for discrimination between two points touched. Work in pairs, using a two-point contact needle. Explore the back of the hand, the palm of the hand, the tip of the index finger, the forearm, the back of the neck; the experimenter touches the skin either with one point or with both points at exactly the same time. (Do not press too hard, as a sensation of pain is different from that of touch.) The subject, not seeing the contact, reports whether he feels one point or two. Test each region a sufficient number of times to determine the smallest distance between points which the subject can detect. Use spreads of 20 mm, 10 mm, 5 mm, 3 mm, and 1 mm.

What are the smallest intervals that could be distinguished in each area?

[1]See footnote 4, p. 183.

8 To show that sensitiveness to temperature may be influenced by temporary conditions, place both hands in a basin of lukewarm water, after one hand has been for a time in very hot water, while the other has been kept in cold water. Describe the sensations in each hand and explain the difference between them.

9 To observe your own progress in learning, time yourself on successive efforts to perform a given task—as writing the alphabet backwards—until further progress is no longer possible. Plot a graph to show the relation of the number of trials to the reduction in time of performance.

QUESTIONS

1 How is an organism equipped to receive significant stimuli, external and internal?

2 To what kinds of stimuli do the specialized sense organs of higher animals respond?

3 What kinds of organs act as effectors?

4 What is a reflex arc?

5 What is meant by a chain of reactions?

6 What is known about the nature of the impulse transmitted by different nerve cells?

7 Of what does the central brain-spine system consist?

8 How are the voluntary movements of our bodies brought about?

9 In what respects is the autonomic nervous system like the brain-spine system? In what respects different?

10 How are the activities of the specialized organs and tissues of higher animals co-ordinated?

11 How do modern living conditions bring special dangers to our sense organs?

1 Do glands influence our abilities?
2 Do glands influence personality?
3 How can a slight change in one part of an organism bring about adaptive responses in other parts?
4 How do gland substances reach other parts of the body?
5 What good does it do living things to feel fear?
6 Are all people naturally or instinctively afraid of the same things?
7 Can we learn to overcome fear or to control anger?
8 Can people act against their instincts?
9 Why do we learn more easily at some times than at others?
10 Can human nature be changed?

When Abraham Lincoln was President of the United States, the country was torn by civil strife. The entire population was constantly agitated by strong feelings—bitterness and hatred, anxious waitings and eager hopes, high elations and shattering disappointment. The President himself, with all his patience, was subject to moods of depression. It was easy to give good reasons why one should be angry at one time and joyous at another. But nobody suspected that "glands" had anything to do with people's feelings.

In the following forty years much was learned from the study of patients in hospitals and clinics, from experiments, and from the comparison of men and women living in different regions under different circumstances. We had already learned enough to suspect that some of President Theodore Roosevelt's characteristics were related to glands, and he was often described as "hyperthyroid".

How can glands influence people's feelings or their behavior? What are glands anyhow? What do they do? How do they produce effects in other parts of the body?

What Are Glands?

The Humors Hippocrates, the most famous Greek physician, advanced the idea that the health of the body depends upon a balance of four master fluids or "humors" within the body. Blood is one of these, the red one; and the others were white, black, and yellow. For centuries this supposition guided the doctors in treating their patients. And it still shows itself in our daily language, for we speak of a person's being in ill humor, or being phlegmatic or melancholic—that is having too much white humor or

too much black humor, or bile. Physicians who accepted this interpretation treated their patients chiefly by trying to increase or diminish the amount of one or the other of these humors, so as to restore the balance.

Chemical Foundations Today we know that the chemical processes in living protoplasm are accelerated or retarded in various ways. The heart-beat, for example, is accelerated by a slight increase of carbon dioxide in the blood (see page 196).

The relation between the behavior of an organ and the chemical conditions is illustrated in certain experiments by the American biologist Jacques Loeb (1859–1924). When Loeb placed strips of a turtle's heart in dishes of salt solution resembling the lymph of the animal, they continued to contract and expand regularly. When he added small quantities of various salts to the different dishes, some of the strips beat faster, some slower. These strips of heart continued to beat for weeks after the rest of the animal had been cut up, some of it destroyed, and all of it "dead".

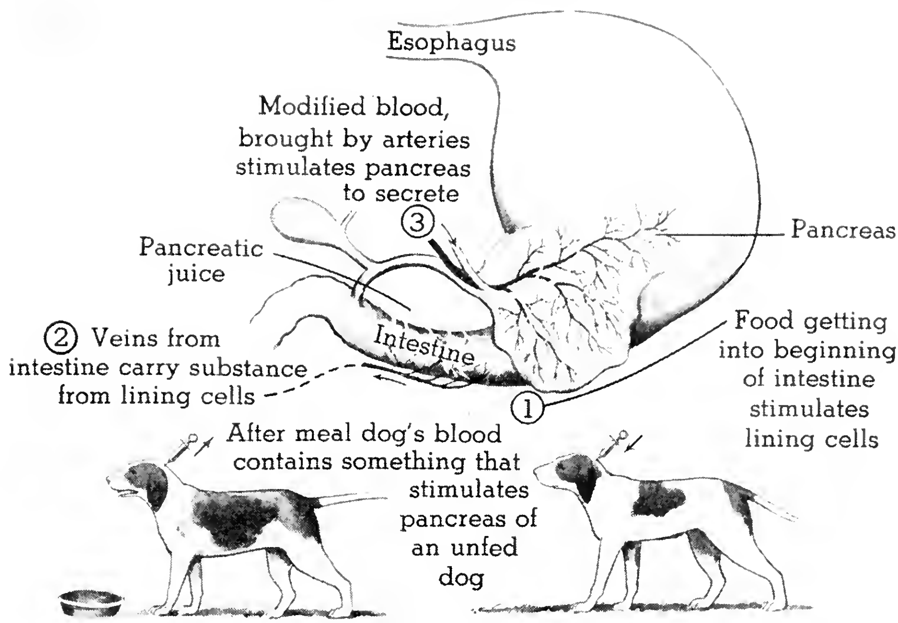
Chemical Factories Metabolism itself results in various kinds of substances, such as carbon dioxide and water, urea and lactic acid, and other waste products. In addition to these oxidation products, every kind of cell produces various special substances. Do not some of these substances influence the metabolism of other cells? Indeed, we have already discovered that very many of the natural "poisons" and "drugs" are themselves a result of plant and animal metabolism.

Glands We have seen that in the digestion of food several special fluids take part—the saliva, the gastric juice, the bile, the pancreatic solution (see page 169). Any organ that produces a specific substance is called a gland.

The glands are richly supplied with blood vessels. They commonly discharge their special products on surfaces lining small cavities or tubes (see illustration, p. 170). The specific product of most glands is secreted or discharged through a special duct or tubule.

In the middle of the last century a famous French physiologist, Claude Bernard (1813–1878), discovered that the carbohydrate reserves in the liver get directly into the blood-stream circulating through that organ. That is to say, a substance can get out of an organ *without passing through a special duct.* It was already known that waste substances are carried off by the blood. But Bernard was impressed by the fact that special and usable products get directly into the blood-stream from the cells in which they are located or formed. That was the beginning of the idea of ductless glands, as we now think of these structures.

Ductless Glands What makes the pancreatic juice come into the intestine when food from the stomach arrives there? What makes bile come from the gall bladder into the intestine just when the food is ready for it



HOW A CHEMICAL MESSENGER WAS DISCOVERED

When some blood from a dog that has just been feeding is injected into the veins of a dog that has been without food for several hours, the pancreas of the hungry dog begins to secrete digestive juices. Otherwise the pancreas becomes active only when food enters the intestine from the stomach

and not at other times? Toward the end of the nineteenth century, two British scientists, experimenting on dogs, found a surprising answer to these questions. They could find no nerve connections to account for what happens. Instead they found that when food arrives in the intestine, some cells in the wall of the intestine start producing a special substance, which is not, however, discharged into the food cavity. This special substance is absorbed by the blood and carried off in the blood-stream.

When blood containing this substance reaches the pancreas or the liver, it starts the gland secreting its special product. How can we tell that it is this something in the blood that sets off the gall bladder and the pancreas? If we take some blood from a dog shortly after food has passed from the stomach to the intestine, and inject it into the veins of a dog whose stomach is empty, both pancreatic juice and bile will in a few moments appear in the intestine of the second dog. William Maddock Baylies (1860–1924) and Ernest Henry Starling (1866–1927), the experimenters, called this unknown substance *secretin*, and described it as a *hormone*, from a Greek word mean-

ing to arouse or stir up. Later an American physiologist showed that secretin consists of at least two different substances, one of them acting on the pancreas, the other on the gall bladder.

What Ductless Glands Are There?

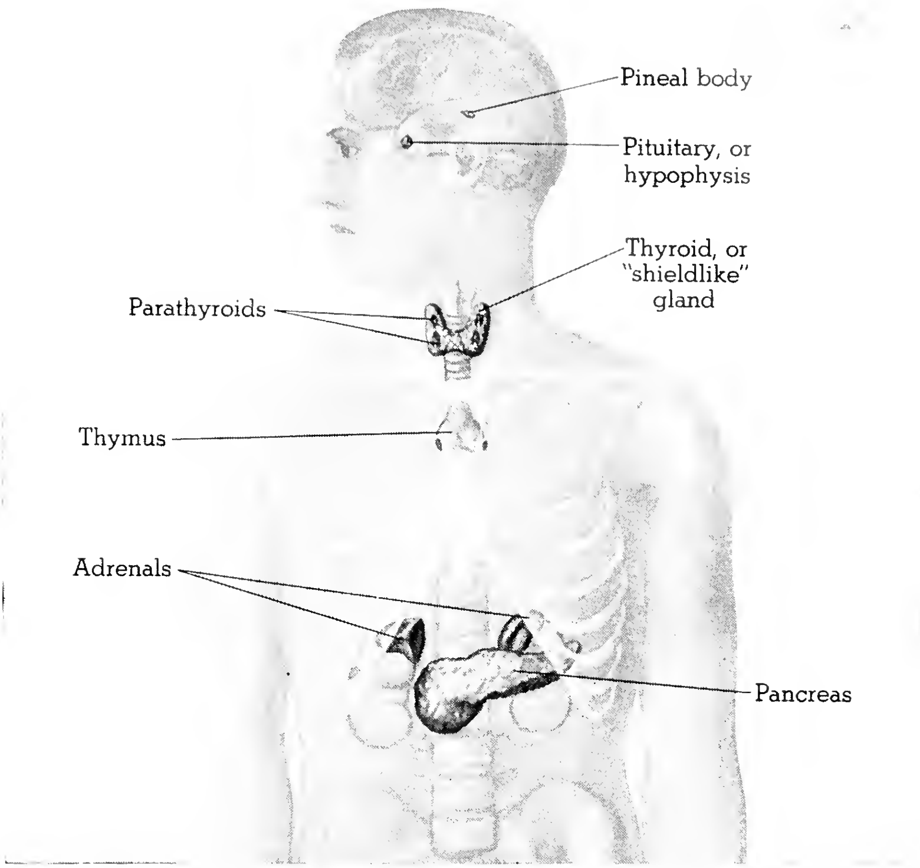
Modern Humors No scientific physician today takes the four humors seriously. For one thing, the number is much too small. Instead of going back to Hippocrates, we now watch a growing list of hormones, specific chemical substances that influence metabolism. The fluids produced by the ductless glands are also called internal secretions, or *endocrines*. Each of these hormones is distinct chemically, and it is distinct in the effects which it produces in the body; but all have certain features in common: (1) they change the rate of metabolism in various cells or tissues; (2) they originate in specific tissues; (3) they are rapidly distributed by means of the blood; (4) they produce effects, although present in amazingly small quantities.

Hormones do not supply fuel; yet they may determine the rate at which energy is released, or whether oxidation takes place at all. Hormones do not supply building material for protoplasm, but they may influence the rate of assimilation, the growth of cells, and the growth of tissue. Some of them arouse chemical actions but others may repress or retard them. An extremely small quantity of a particular hormone may at any moment determine the issue between life and death.

The Endocrine System[1] At present at least eight or nine distinct structures have been sufficiently studied to be classed as hormone-producers. Besides the ductless glands shown in the diagram on the opposite page, the reproductive organs, or gonads (ovaries and testes), also produce hormones in addition to the reproductive cells (see page 379). Scattered throughout the body are small groups of cells that behave like some of the endocrine tissues. Although every one of the endocrines is distinct, each may reinforce or counteract one or several of the others. Taken together, therefore, they behave like a unified system; and as each hormone influences the various organs and tissues and processes in a distinct way, the endocrines play an important role in unifying the several parts of the entire organism.

One interesting feature of the endocrines is their great similarity in all mammals and probably in all vertebrates. This has made it easier to carry on research by trying out our problems and hypotheses on various smaller animals, and also to make use of new discoveries. If a human being is deficient in the pancreatic hormone, for example, the shortage can be made up by using extracts from the pancreas of a sheep or an ox or a pig.

[1]See No. 1, p. 320.



LOCATION OF ENDOCRINE GLANDS IN THE HUMAN BODY

The glands of internal secretion produce substances that are distributed by the blood and produce effects in remote parts of the body. Their names tell us nothing about their functions. The name "hypophysis" means merely "under-body", from its position under the brain. Adrenals are next-to-kidneys, while para-thyroids are beside-thyroids. The names "thyroid" and "pineal" refer merely to shapes. The pineal gland was supposed by Descartes to be the "seat of the soul"

About a dozen hormones have been recognized. About half of these have been obtained in a pure crystalline form of a definite chemical composition. A few have been reproduced synthetically. Several of the endocrine organs produce more than one kind of hormone. The thyroid, like the paired parathyroid, however, produces one particular kind of hormone and nothing else, although each hormone may produce more than one kind of effect.

The Ductless Glands and the Hormones

[The location of the endocrine organs is shown in illustration, p. 305.]

GLAND AND HORMONE	NORMAL FUNCTIONS	EFFECTS OF DEFICIENCY	EFFECTS OF EXCESS
Thyroid *Thyroxin*	Influences development and maturing Stimulates metabolism, especially oxidation	Cretinism Myxedema	Exophthalmic goiter
Pineal, "epiphysis"	Influences development and maturing	Accelerates sexual maturing Retards growth	Retards sexual development
Parathyroid	Influences bone formation; phosphorus and calcium metabolism; effectiveness depends upon vitamin D	Spasms, cramps, convulsions related to low calcium level in the blood	Abnormalities of bone and skin; weakening of bones by removal of calcium Possible factor in shrinking of skeleton in old age High calcium level in blood, a possible factor in sluggishness of muscles
Pituitary, "hypophysis"			
A. Anterior lobe			
Somotropin	Influences growth of whole body and of special parts, as the long bones	Dwarfism	Gigantism; enlarged hands and features
A "fat-metabolism" factor	Stimulates oxidation of fats		
Gonadotropins	Stimulate development of sexual organs	Prevent maturing	Accelerate sexual development
Prolactin	Stimulates development and action of milk glands; arouses "mothering instinct"		
Various	Stimulate growth and activities of other ductless glands	Disturb harmonious growth and activities of the other ductless glands	Disturb harmonious growth and activities of the other ductless glands
B. Posterior lobe			
Pitressin	Regulates water level in blood Raises blood pressure and slows heart beat by contracting smooth muscles of blood vessels	Causes excessive loss of water through kidneys Apparently results in obesity	Prevents normal excretion through kidneys
Pitocin	Contracts smooth muscle of intestine and uterus Stimulates peristaltic action		

Adrenals, "suprarenal capsules"			
A. Medulla, or core			
Adrenin, or *epinephrin*	Accelerates and regulates metabolism Increases formation of sugar in liver Affects circulation by acting on muscles of blood vessels Reduces fatigue Interacts with sympathetic part of autonomic system	Reduces metabolism and assimilation Lowers blood pressure Disturbs blood vessels of digestive system Stirs up feeling of distress, anxiety	Accelerates heart action Drives blood from abdominal organs to heart, lungs, skeletal muscles Contraction of smooth muscles raises blood pressure Cold perspiration Stirs up feeling of excitement or agitation, fright
B. Cortex, or rind			
Cortin	Essential to life Maintains basal metabolism and work capacity Hastens recovery from fatigue Promotes resistance to infection Interacts with pituitary Affected by deficiency of vitamin B_1	Loss of water from blood and lower blood pressure Lowers sugar level and basal metabolism Weakens muscles Raises phosphorus, potassium and calcium levels in blood In childhood, retards sexual development Addison's disease, characterized by languor, weak heart action, low blood pressure, discoloration of skin	Raises blood pressure During development, obstructs differentiation of male and female organs In childhood, accelerates sexual maturing Later, tends to stimulate development of masculine secondary traits in females
Thymus (hormone not isolated)	Stimulates growth; counteracts developmental and maturing processes	Accelerates maturing in advance of growth Dwarfism	Delays sexual development; retention of childish characters
Pancreas, isles of Langerhans			
Insulin	Controls formation of sugar from fats and proteins in cells of liver Regulates sugar metabolism	Excess of sugar in blood Inadequate oxidation of carbohydrates in tissues Diabetes	Lowers sugar level in blood May lead to failure of respiration and to convulsions
Gonads			
A. Ovary			
Estrone	Stimulates normal development of secondary female characters Regulates activities of female reproductive system Interacts with pituitary		
B. Testes			
Testosterone	Stimulates development of secondary male characters Interacts with pituitary		

Chemical Activators The endocrine glands are stimulated to secrete by nerve impulses, primarily by those from the autonomic nervous system. They are also influenced by chemical changes in the blood and by hormones from other glands. The hormones, the specific products of the endocrine glands, have been called "chemical messengers". In their rapid distribution they act like nerve impulses, which arouse action at points remote from a stimulus: something happens here and sets offs some action there.

Since the blood keeps the fluids of the body constantly stirred up, these chemical messengers take part in all that happens in the body. They produce effects in all parts of the body, and events in the various organs constantly influence the kinds and amounts of hormones secreted. Like the nervous system, the endocrine system keeps all the parts in constant communication. We consider the endocrine system as "older", or more primitive, than the nervous system; for among simpler organisms that have no nervous structures, the protoplasm is sensitive to chemical stimulation, and it also responds to stimuli with chemical changes. Moreover, the hormones operate in higher vertebrates, like ourselves, for example, without producing sensations and without seeming to stir the "newer" parts of the nervous system to consciousness.

What Do Hormones Do?

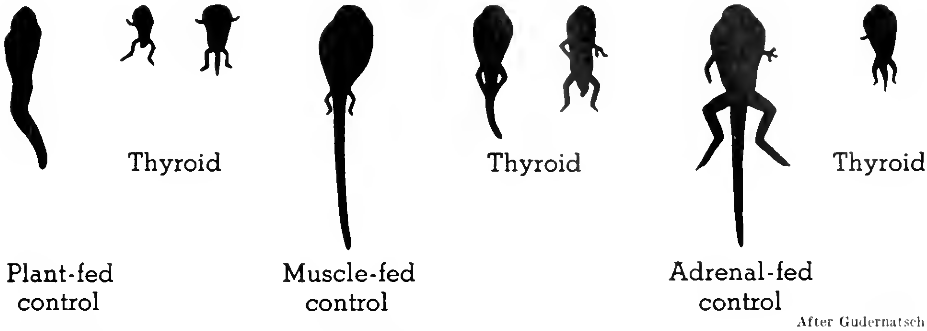
Temporary Service The *pineal* gland and the *thymus* (chest sweetbread at the butcher's) seem in all mammals to be active only during the early period of life. That is, the structures normally shrink away before sexual maturity is reached. The relation of the pineal structure to life processes is still very uncertain; but when the organ is injured, the results suggest a specific hormone which influences sexual development.

Hormones and Growth Some hormones accelerate growth, either of the whole organism or of special parts. When the thymus, for example, is injured or removed, as through disease, the organism is stunted. When it is overactive, the body grows very rapidly. In certain experiments J. F. Gudernatsch, of the Cornell medical school, fed some tadpoles on thymus glands obtained from calves, and others on thyroid material. The first lot of tadpoles grew to a large size, but remained tadpoles. The second lot, however, quickly passed through the stages of development without increasing much in size (see illustration opposite).

In human beings the thymus reaches its greatest relative size during the second year. Where, for any reason, the thymus persists past puberty, the person remains childish in many ways; that is, he fails to mature physically, intellectually and emotionally.

One of the several hormones found in the front lobe of the pituitary also

influences growth (see illustration, p. 310). If the pituitary becomes overactive after the long bones have reached their normal full growth, the



INFLUENCE OF THYROID ON DEVELOPMENT

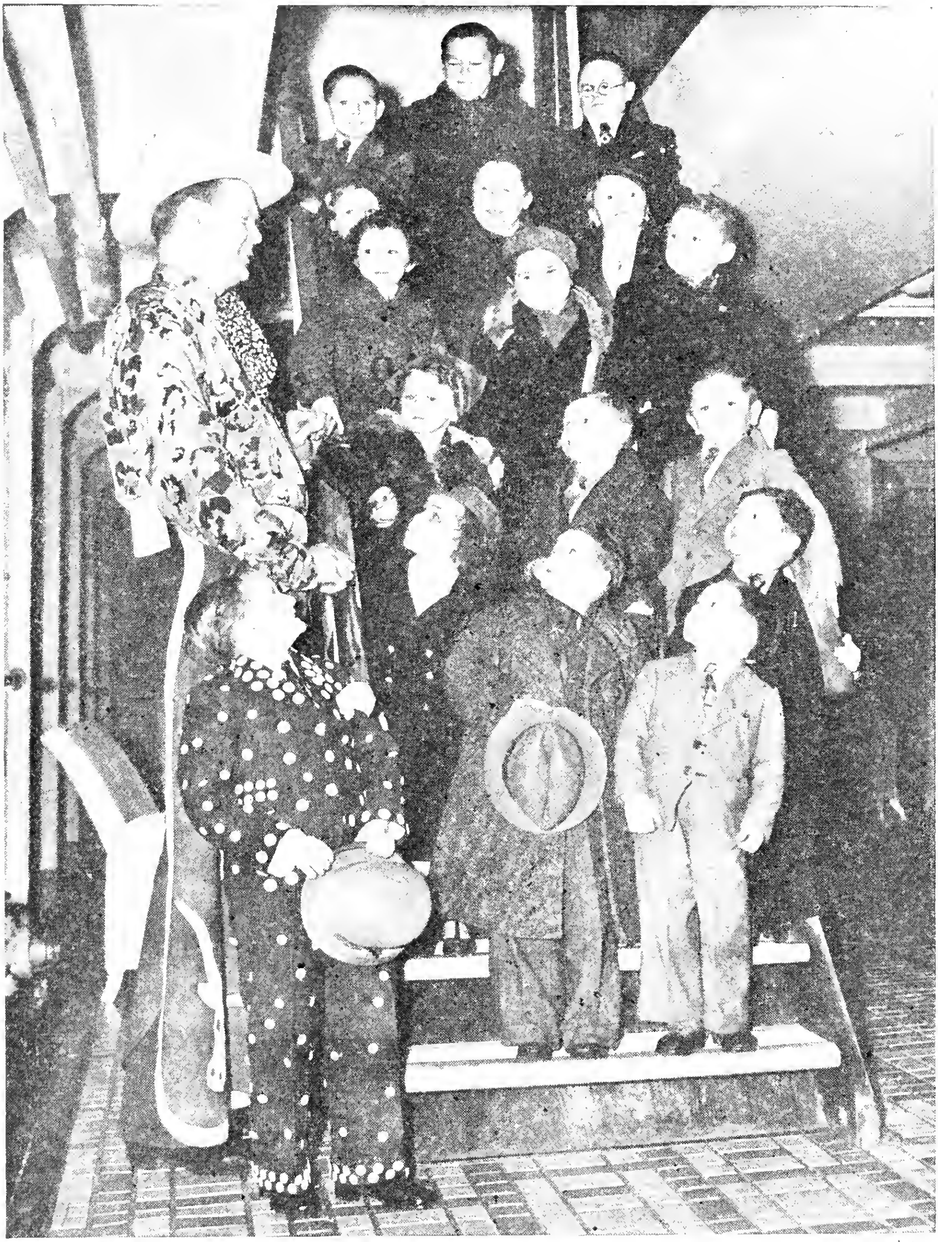
In three series of experiments, young tadpoles fed on thyroid tissue developed toward adult stage so rapidly that they hardly had time to grow. These are full size

bones of the face, jaw, hands and feet may now continue to grow. Such disproportionate enlargements of the face, the nose, the lips and the hands are often very distressing.

Hormones and Development As an organism increases in size, it normally changes also in proportions. Everybody recognizes that the body of a mature person is in many ways different from that of a very large baby (see illustration, p. 347). In bodies like our own the maturing appears to be related to the rate of metabolism. But the rate of metabolism is in turn very much influenced by the hormones, especially by *thyroxin*, the thyroid hormone (see illustration above).

Where the thyroid is deficient at birth or in early infancy, the child remains sluggish, sometimes to the point of being idiotic. This is not the same as being born with a defective brain. It means that although all the parts of the organism are present, they are not operating effectively. Children in this condition, called *cretins*, have appeared in some regions in much larger proportions than in others. In fact, it was long generally believed that the population of certain parts of Switzerland and of other mountainous regions were degenerate because there were so many cretins among them. It was assumed that this condition was inherited and represented a defective stock.

In recent times, however, we have learned to distinguish idiocy, due to defective brain development, from cretinism, due to a thyroid deficiency. Moreover, we have learned to *cure and prevent cretinism* (see illustration, p. 311). The hormone produced in the thyroid has been chemically identified and is today produced synthetically. It is distinguished from most other organic compounds by the presence of iodine. Where the soil—and the food



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DWARFS AND GIANTS FROM CHEMICAL ACTION

An excess of the hormone produced by the anterior lobe of the pituitary seems to cause the excessive growth of giants, while a deficiency retards growth so that one may reach his full development while still no larger than a child

COMPENSATING FOR THYROID DEFICIENCY[1]

Thyroid deficiency sometimes retards a child's development, both mentally and physically. A "mongoloid" cretin treated with thyroxin showed steady improvement. Many such cases are being restored to normal life

raised on the soil—lacks iodine, the thyroid cannot develop adequately, and human beings and other mammals suffer accordingly. In this country several regions are lacking in iodine sufficiently to bring about a condition known as simple goiter in a large proportion of young people, especially girls (see map, p. 101). This is a slight swelling of the thyroid, which has been cured. It ordinarily disappears, however, in a few years. At present, however, this type of goiter is being completely prevented in entire populations by adding small quantities of iodine to the common table salt.

Hormones and the Rate of Metabolism[2] In addition to influencing development during early stages, thyroxin influences the rate of metabolism at all stages. An excess of thyroxin leads to an overdriving of all the body's activities. This means increased oxidation; and if food is not supplied in suitable proportion, the organism oxidizes its reserves and loses weight. The speeding up of metabolism results also in higher body temperature and in general nervous excitement. There may be drying of the hair and excessive perspiration. Sometimes the eyeballs protrude while the lids are held wide open. Such cases are frequently helped by the removal of a portion of the thyroid.

Since excessive thyroid activity increases the oxidation of fats and carbohydrates in the body, some people have used thyroid extract for reducing body weight. But this is a dangerous practice and should in no case be followed except under the direction of a physician.

[1]From *Lectures on Endocrinology*, by Walter Timme, published by Paul B. Hoeber, Inc.
[2]See Nos. 2 and 3, p. 320.

In time of extreme excitement or emergency, an increase of thyroxin in the blood makes possible an exceptional output of energy. When thyroxin is continuously present in excess, the alarmed look and high tension indicate a disproportionate discharge of energy, with the danger of exhaustion

EXOPHTHALMIC GOITER[1]

A significant clue to the ductless glands, and especially to the thyroid, was furnished by observations made in England on middle-aged women suffering from *myxedema.* In this condition of disturbed metabolism patients have cold hands and feet, a bloated appearance, thickened lips and tongue, coarsened skin, a dull feeling, and loss of memory. It had been observed that in such patients the thyroid had shrunk or deteriorated. In 1891 a British physician treated one such case with the dried thyroid of sheep. He restored his patient and kept her alive and in normal health for twenty-eight years, until she died at the age of seventy-four.

Hormones and the Release of Energy In the cylinders of a gas-engine the energy-releasing explosion of the fuel-oxygen mixture is set off by a spark. In the protoplasm of a mammal's body the oxidation of sugar or other fuel depends upon the hormone *insulin.* This hormone was extracted from the pancreas by two Canadian scientists, Frederick Grant Banting (1891–1941) and Charles H. Best (1899–). The men were following up a thirty-year-old clue from Strassburg. There a physician in the hospital noticed that flies were clustering in one pen of dogs being kept for medical experiments, but not in the neighboring pen. Since the pancreas had been removed from some of the dogs, Dr. Naunyn immediately suspected that the treated dogs were suffering from *diabetes,*—a condition in which there is an excess of sugar in the blood and urine. Through further experiments it was established that this disease is due to defective action of the pancreas—not of the liver, from which the reserve glucose gets into the blood.

[1]From *The Endocrine Glands,* by Max Goldzieher, published by D. Appleton-Century Company, Inc.

Insulin is not a cure for diabetes, for a deficient pancreas remains a deficient pancreas. Insulin obtained from the pancreas glands of cattle can be used to make up for the body's deficiency. By attending to his diet and adding insulin regularly to the blood-stream, a person suffering from diabetes may continue to live with a deficient pancreas and carry on his normal activities for many years. People often ask, Why should not the insulin or pancreas tissue be taken in with the food? The answer is that the digestive fluids, including those of the pancreas itself, destroy insulin.

Hormones and Emergencies In our day-by-day activities the exertions and energy output of the body are constantly changing. Changes in the secretion of insulin and thyroxin accompany changes in the rate of metabolism, the rate of breathing, and the pulse rate. Through these variations the organism adjusts itself minute by minute. An emergency, however, places exceptional strains upon the body. A situation may threaten one's safety or arouse one's rage.

When the organism is under great stress the adrenals come into action, stimulated by a nerve impulse from the autonomic system. The medulla, or core of the adrenal capsule, discharges into the blood the hormone *epinephrin*, sometimes called also *adrenin*. Like thyroxin, epinephrin accelerates the general metabolism of the body, but it does not act equally on all parts. We have no sensation in the adrenal, and we cannot "feel" the epinephrin in the blood. But the changes produced by epinephrin are obviously adaptive. When the hormone is in the blood, it increases the fuel and hastens the blood-flow to the muscles; it raises the tension of the muscles, widening the nostrils and deepening the breath, setting the eyes and all the senses on the alert. A person who shows some of these characteristics under normal conditions probably has an excess of epinephrin in his blood (see illustration, p. 314). In many cases such a person is likely to make trouble for others, or for himself.

Adrenin decreases the blood supply to the digestive system, but makes more blood available to the muscles. It seems to reduce fatigue even while energy output increases. When the amount of this hormone is increased by great excitement or sudden fright, the skin turns white, the eyes open wide, the heartbeat is accelerated, and blood pressure rises. The organism is all set for fighting or for running away. If it sustains its effort under high tension, epinephrin continues to come into the blood. The effect is to raise the entire level of energy output to what athletes sometimes call "second wind".

After the emergency is over, the metabolism in the various organs and tissues returns to the usual rates. From our own experience we know that after any great excitement we are actually weaker than at ordinary times. In fact, we nearly always feel a decided letdown after any excitement.

The cortex, or rind, of the adrenal produces another hormone, called

High blood pressure, high pulse rate, bulging eyes, and emotional tension are characteristic of certain conditions which the individual "feels" and which are often associated with excessive thyroid secretion. Experimental treatment showed that in this case the condition was due to an excess of adrenin

ACTION OF EPINEPHRIN[1]

cortin. Cortin seems to have some relation to the water-and-salt balance of the blood and to the body's resistance to infection. Like insulin, cortin increases the oxidation of glucose. Cortin seems also to influence the development of the reproductive organs, probably by interacting with the hormones of the pituitary gland.

The Master Gland The most complex of the endocrine organs is the pituitary, which has been called the "master gland" because the several distinct hormones which it produces affect various organs and various processes in important ways. The hormones of the pituitary interact with the other endocrine organs. As a result, they have the effect of maintaining a balance among the various processes of the organism. But, because they interact, a serious disturbance of one endocrine may cause a serious disunity in the growth, development, or activity of the whole organism. As we have already seen, one of the pituitary hormones affects the rate of growth (see pages 308-309).

Glands of the Reproductive Organs The ovaries and the testes of backboned animals produce respectively the eggs and the sperm (see pages 379-381). Among the cells that form sperms or eggs, but apparently not directly connected with them, are other cells that produce special hormones. We might compare these hormone-producing cells of the gonads with the islands of the pancreas. The so-called sex hormones appear to be especially related to the "secondary sexual characters"—that is, the features that distinguish male individuals from female individuals. They include the distribution of hairs, pigmentation, horns, the voice, the development of the milk

[1]From *Lectures on Endocrinology*, by Walter Timme, published by Paul B. Hoeber, Inc.

glands, and other features that distinguish the two sexes among birds and mammals. These are called secondary characters because they are not primarily related to the reproductive function (see pages 391–393).

One of the pituitary growth hormones stimulates the development of the gonads. When these reach a certain stage, they discharge into the blood their own specific sex hormones. One of these in turn acts upon a portion of the pituitary gland so as to stop its further secretion of growth hormones. As a consequence, the general growth of the body is likely to stop about the time when reproductive organs mature. If their maturing is delayed, general growth may continue further.

What Have the Hormones to Do with the Feelings?

Hormones as Unifiers During an emergency the appearance and the behavior of a person (or of any other animal) change decidedly. The internal organs also change their action. Such situations arouse distinct feelings. You feel a tingling in the skin, or you feel a difficulty in breathing. You feel your heart thumping or perhaps some of the arteries in the head throbbing. In addition to such feelings, however, there are others which we cannot so clearly locate in any one part of the body. When you are frightened, for example, you are frightened all over. When you are angry, you are angry all over. When you are glad, you are glad all over, not merely in the eye that sees the pleasing object or reads the happy news. Whatever happens, you are normally *all set*, to take it—or to fight it, or to run away.

Organic Sources of Emotions In general, emotions accompany the organic processes that have to do with keeping alive or with preserving the species. In the case of nutrition, for example, we may become so hungry that we are driven to get food through special effort. We cannot keep quiet, and we get no rest or satisfaction until food is obtained. If the hunger makes us *do* something, we speak of the emotion as a *motive*, or *drive*. In fact, the word *emotion* means that which *moves* one to action. There may be great discomfort or dissatisfaction, a desire for something, and finally a deep satisfaction when the desire is fulfilled. We say in such cases that the emotion is one of *relief* from a previous strain.

Joy and Sorrow Agreeable emotions are associated with the healthy workings of internal organs, with the satisfying of desires, and with activities that lead toward such satisfying. Merely hearing sounds or swinging the arms, or merely shouting or walking may yield such satisfactions. Disagreeable emotions are usually aroused by internal strains or by any *interference* with desire or activity. If the urine is retained too long in the bladder, if somebody blocks your path, if your wishes are denied you, unpleasant feelings are aroused. Even holding a baby's head firmly, without

HAVING FUN

For the young child all experience, all action, all sensation, may yield satisfaction and pleasure. It is only later that his play or fun takes on the form of games, or of activities that have a purpose. It is fun to be alive and to feel the touch of the world as it strikes us—not too hard, of course—and as we impress ourselves upon it

Child Study Laboratory, Vassar College

LET GO!

Anything that interferes with our free movements arouses anger. Learning to control our anger may mean learning to sense the difference between important situations and those that do not matter. But it may also mean letting others dictate our way of living, always hating them for it, but afraid always to show our resentment

producing any pain whatever, is enough to make him very angry. Free, spontaneous, satisfying activity, and healthy, vigorous, smooth working of the internal organs—such are the bases for the joy of living. Restraint, coercion, frustration in action, or flabby, inharmonious, or perhaps even painful working of the organs—such are the bases of sorrow, distress, and disgust with life.

Many people belittle our moods or emotions as being "only states of mind". But these states of mind are the very substance of what we value in life, as they are the drives that make our lives go on.

We must not expect a particular emotion for each natural act or impulse. Moreover, our natural responses become *conditioned*. We acquire particular tastes and aversions through our experiences. We respond one way to per-

sons we like and differently to those we dislike. We respond in a particular way to our school or national flag; others respond in a similar way to other stimuli—that is, to *their* schools or flags.

Organic Aspects of the Emotions[1] When a person is angry, he sometimes acts violently. We say, "the blood rushes to the head"—and it does. He "sees red"—but not clearly. Instead of thinking clearly about what he needs to do or how to do it, he is apt to act wildly.

When anger is aroused, one may be "white with rage". A rapid increase of epinephrin in the blood makes the fine capillaries of the surface circulation contract. But it also raises the blood pressure and presently one can be red with rage. The rapidly diffused adrenin increases the flow of blood to the skeletal muscles, which become tense, ready to act promptly and powerfully; but it has an opposite effect upon the circulation of the digestive tract. Even a young child can discover that when strong feelings are aroused, he does not feel like eating; and it is not wise to urge food at such times. As the stomach and the intestines stop all glandular and muscular work, one may suffer acute indigestion. Under a strong emotion one may "feel sick at the stomach".

These changes in the circulation of the blood and in blood pressure are not ordinarily apparent to the observer. But we know from experiments that they are as truly parts of the emotions as the feelings themselves, as the facial expressions, and as the changes in behavior.

In the case of fear, we may find many departures from the normal besides those of the facial expression. On the other hand, it is possible for one to be "consumed by jealousy" or by curiosity without showing it outwardly, at least without showing it in a way that most of us would recognize.

Whatever happens to the emotions *influences the whole body*, probably through the chemical effects of substances from the ductless glands. The experiences and activities of the whole body in turn modify the ductless glands and the emotions, probably through the reflexes of the autonomic nervous system. It is said that when one is frightened and starts to run, the movements and the whole attitude of the body will tend to strengthen the fear feelings. If, on the other hand, one faces the object of fear and begins to *act* against it, those feelings soon evaporate. This is so true that we can see every day the relation between a person's posture and his habitual disposition. The sergeant may be able to force the recruits to stand up like soldiers, but unless they somehow learn to feel like soldiers, they will slump into some other way of standing as soon as the discipline is withdrawn.

Kinds of Learning A person cannot help becoming hungry when he has been short of food for a long time. The nature of the organism compels a certain emotion under certain conditions. But the manner of satisfying

[1] See No. 4, p. 320.

Acme

An angry person does not see very clearly; he cannot calculate his movements and place each stroke where it will do the most good. He may act with all his energy — but he acts wildly. The calm person acts deliberately, intelligently. He knows exactly what he wants to do, and how to do it. But his action usually lacks drive. It takes training and self-control to enable one to punch with all his might and yet make every stroke count

TRAINED ACTION

our hunger is largely within our control. Hungry people have fought one another for food; that is one way. Hungry people have gone out to hunt game, or they have organized work that would bring them food; that is another way. Even at the table you can see hunger driving some people into one kind of behavior and others into a different kind. The different behaviors of hungry people show that we can acquire not only different kinds of action "habits", but also different kinds of emotions or feelings about things and activities, about ourselves and about other people.

These feelings which incline us to act one way rather than another, or which make us favor some kinds of dealings or relationships and turn away from others, we call *attitudes*. These attitudes, like tastes, are no doubt due in part to natural individual peculiarities. To a certain degree, however, they can be learned or acquired through our experiences. These attitudes are quite as much a part of our behavior as the natural and unconscious responses of our internal organs or our reflexes or chemical adjustments, and as much so as the things we do intentionally. In fact, *our whole manner of living* represents a scheme in which emotions, thoughts and actions are all parts of a unity. One who shows what we call breeding, or good manners, at table has a different set of feelings from one who shows bad manners. Both may be equally hungry. Differences in behaving represent differences in ways of feeling and thinking, not merely differences in "habits".

If a baby is accustomed to feel the joy of satisfied hunger immediately after hearing a certain sound, he will soon come to have that joyous feeling on hearing the sound. If people discover that controlled anger brings more satisfaction than uncontrolled anger, they will in time find a way to control anger.

The habits that we acquire all involve feeling, as well as thinking and

doing. The nerves, reaching all parts of the body, are sensitive to changes and in turn bring about changes. Again, the blood, reaching all parts of the body, is altered chemically by slight changes in any set of organs, and so brings about important changes in the activity of protoplasm in all parts of the body. In this way emotions influence our thinking, our actions, and the behavior of the internal organs. On the other hand, both our thinking and the action of the skeletal muscles can modify our emotions.

In Brief

Since the time of Hippocrates, people have associated temperament and illness with the fluids, or "humors", of the body.

In the higher animals the rate at which the chemical processes in the living protoplasm go on is influenced by the amounts or proportions of certain specific substances in the body fluids.

The ductless glands are special organs that produce and discharge specific substances directly into the blood. Distinct from one another, they are closely related in a system of interactions.

Everything that modifies the normal action of any of the internal organs at once brings about an increase or decrease in the secretion of one or more of the ductless glands.

The internal secretions of the various ductless glands, called hormones or endocrines, are rapidly distributed by the blood and act in amazingly small quantities to stimulate action in various organs, including other ductless glands.

The endocrines of all the mammals are very similar, so that it is possible to use animal extracts in making up human deficiencies.

Some of the endocrine glands act throughout life, others for only a relatively short period; some produce but a single known hormone, others produce several hormones; some of the hormones secreted have but a single known effect, others have multiple effects.

Hormones modify the basic protoplasmic activities: some affect growth and development, some sensitiveness to external conditions, some the use of energy in movement or other activities.

In higher animals, emotions seem to accompany the processes that have to do with preserving the organism or the species.

Whatever happens to the emotions influences the whole body, probably through the chemical effects of the substances from the ductless glands; the experiences and activities of the whole body in turn modify the ductless glands and the emotions.

1 To find the location of the various endocrine glands, dissect a thoroughly anesthetized laboratory animal, identify from charts and examine the form, structure and texture of as many of the glands as possible.

2 To demonstrate the effect of thyroid extract, feed animals on diets that differ only in its presence. Place a male and a female rat, from three to four weeks old, in each of two cages; feed both pairs the same diet.[1] To the rats in one cage feed, in addition, half of a one-tenth-grain tablet of thyroid extract each day. The half tablet must be placed in the mouth of each rat to make sure that it is taken in. Keep record of weight; make a graph of daily growth. Compare the behavior, as well as the growth, of the rats in the two cages. In what ways does the thyroxin seem to affect the personality? Compare results of this experiment with known cases of hyperthyroid persons.

3 To find the effect of thyroid extract on the development of tadpoles, feed two sets the same diet, but supply one set with thyroid extract. Place the tadpoles from the same batch in two aquariums. Feed both sets on flour, but add to the flour for one set a crushed tablet of thyroid extract. Continue watching for several weeks. Describe the differences observed between the two sets of tadpoles.

4 To demonstrate the relation of emotions to muscular activity, to facial expression, and to posture, observe your classmates under various situations that involve distinct emotions or attitudes. What facial movements are involved in "registering" anger, anxiety, fear, affection, cruelty, or eagerness?

Have an individual with his back to the class assume postures intended to express distinct emotions, and see how generally the intent can be recognized.

Attempt to combine posture and gestures of one mood with an imaginary situation that would put one in a *contrasting* mood. For example, try to *look* friendly and helpful while *imagining* yourself in a situation that would make you feel resentful or full of hate—or vice versa. Or try to look as if you were having a hilarious time while imagining yourself at the funeral of a person you love and respect—or the reverse. In each case, note the movements or combination of movements that appear especially appropriate, or especially inappropriate, for the mood or emotion under consideration.

QUESTIONS

1 What factors influence the rates at which the various chemical processes take place in higher animals?

2 In what respects are the hormones like vitamins? like enzymes? unlike either vitamins or enzymes?

3 How are the internal secretions distributed throughout the body?

4 Which of the specific hormones affect growth? Which affect energy liberation? Which affect the rate of metabolism?

[1]The complete diets suggested on page 112 are suitable. A half-and-half mixture of rolled oats and whole-wheat flour, with milk to drink, is very satisfactory. Certain prepared dog biscuits are good.

5 In what respects are the various endocrines independent of one another? In what respects are they interrelated?

6 Which ductless glands operate only temporarily? Which permanently? Which operate under special circumstances?

7 How does the endocrine system operate when the body is in an emergency?

8 How are the various ductless glands co-ordinated in their activity?

9 How are the ductless glands affected by the emotions?

10 How are the emotions affected by the internal secretions?

11 In what ways are the endocrine systems and the hormones of various mammals alike?

12 To what extent does the endocrine system regulate and co-ordinate the organs and tissues of the body independently of the nervous system?

13 In what ways are the nervous system and the endocrine system related?

14 In contrast to the natural expressions of the emotions, how does a good actor bring about the "registering" of various emotions?

1 Can a part of an animal continue to live away from the rest?
2 How much can an animal have removed from its body and still remain alive?
3 Can any animal grow into an entirely new individual from one portion, as many plants can?
4 Are there any plants that die if certain organs are removed?
5 Can one live without a stomach?
6 Can any of the organs be spared?
7 If a tooth is removed, will another grow to take its place?
8 Can any destroyed organs be regrown?
9 If a kidney is removed, does the remaining one do double work or grow to double size?
10 When an animal dies, do all the parts die at the same time?

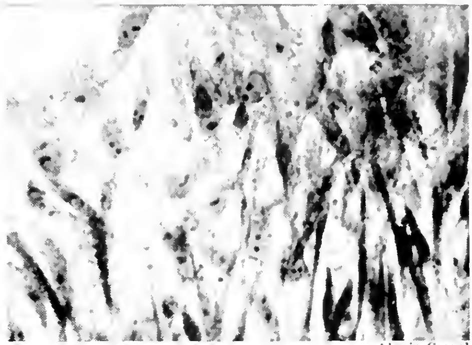
Living things occur in nature as wholes, and they behave as wholes. We find many thousands of distinct kinds of plants and of animals; but unless something has gone wrong, there is in each case a *whole* fish or bird or worm. We do not find, in nature, legs or eyes or clamshells, except as these parts have been removed from whole organisms. When a part has been removed, it no longer acts as it did when it was still with the other parts. But while the parts are together, they behave in relation to one another and in relation to the whole in a very distinct way, so long as there is life. What makes the parts of a living thing all work together as they do? Why cannot the parts behave in the same way when they are separated?

Why Cannot Separate Parts of Living Things Continue to Live?

Anatomizing Life has been so hard to understand that we have felt obliged to take plants and animals to pieces in order to study the organs or parts. For four hundred years the study of medicine has rested on the *anatomy*—that is, the "cutting-apart"—of the human body. We have divided the various organs into their tissues and cells. These we have taken apart chemically, to find out of what substances they consist. We have carried our anatomizing so far that we often overlook the *life* which we started out to find.

Living Fragments Although living organisms in nature occur only as wholes and act as wholes, it is possible for fragments to continue alive. We all know that it is possible to remove a portion of a tree or of a worm without killing it. And we know that the portion removed may become a whole organism. If, however, the fragment does not regenerate, it dies.

Lederle Laboratories, Inc.



Alexis Carrel

THE CULTURE OF IMMORTAL CHICKEN TISSUE IN THE LABORATORY

In 1912 Dr. Alexis Carrel of the Rockefeller Institute removed tiny pieces of heart muscle from a chicken embryo still inside the egg shell, at about the ninth or tenth day of hatching. He placed these fragments in a nutritive medium, kept at a suitable temperature and supplied with air. Every two days the growing piece doubled in size; it was divided, and a part placed in a fresh medium. This has been going on for all those years. Most of the new growth has, of course, been thrown away; if all had been allowed to grow, there would not have been room enough for that chicken heart in all the world

It has been possible in the laboratory to keep a part of an animal "alive" without regeneration. There are the fragments of a turtle's heart which Loeb kept beating away for weeks (see page 302). Even more striking are the experiments of Alexis Carrel (1873–), who started cultures of chicken tissue that have been kept going for over thirty years (see illustration above). We may consider these tissues as "alive", for they grow and produce more cells like themselves. But they are hardly living chicken. They can do nothing that is typical of the life of a chicken. The growing lump is not a whole, although it continues to carry out life-activity in part.

With the assistance of Colonel Charles A. Lindbergh, Carrel later developed a more complex apparatus which supplies a rather large piece of tissue, or even an entire organ, with food and air, maintains a suitable temperature, and removes the products of metabolism. If we had a whole set of such organs, even *all* the organs of any particular animal, we still should not have a living animal—a chicken or a dog.

These "cultured" cells or organs are unable to supply themselves with food, air, or water. They cannot keep themselves warm. They cannot protect themselves. They cannot develop, but merely continue to grow only as material is supplied them by the laboratory attendants.

To be sure, there are species of living things that depend in a similar way upon others. There are, for example, parasites living in the bodies of larger organisms, where they find the materials and conditions essential for

their living (see page 177). Such parasites, however, do act as *whole* organisms; they grow to maturity and reproduce themselves, even if they do not rush around for supplies.

To understand the human body or the body of any other living thing, we have to study the parts. But when we analyze and anatomize, we find that all the chemical elements in living bodies are present also in nonliving things, although there they never form the same compounds. We find too (see pages 19–20) that whatever goes on in a living thing may go on also in nonliving things, although the various processes are never carried on together in any nonliving thing. The parts of living beings may all be the same as the parts of nonliving things; but the combination of parts in a living thing is always unique, and it always acts as a whole. However thoroughly we come to know the details, the details themselves have no meaning except in terms of the whole animal or plant.

What Brings About the Wholeness in a Living Thing?

Wholes before Parts Before we can buy a steak, some apples, or a fur coat, somebody has to raise entire cattle or apple trees, or a hunter has to get a whole fox or rabbit. Our earliest experiences are with entire plants and animals, entire human beings. In time we come to give attention to the separate parts that we can use or to the parts that become injured and so destroy the unity or effectiveness or well-being of the whole. And in time we come to wonder how such diverse parts as we see in any common animal or plant can keep working together.

The microscope enables us to get more detailed information about the parts of plants and animals. Most helpful has been the study of one-celled organisms, in which the *wholeness* does not seem so hard to understand. The parts here are all so close together, so directly connected, that we can hardly see how any part of an ameba, for example, could be disturbed without affecting all the rest. In the larger and more complex organisms the connections are not so obvious. How does seeing an object at a distance make all the muscles change their tensions or movements, or make the hair stand on end, or change the rate of breathing? How does an odor bring a happy expression to the face, or how does another odor "turn the stomach"?

If we find it easy to see how the one-celled organism acts as a whole, it may be helpful to remember that every larger organism *was once a one-celled being.* The wholeness of a horse or a fish has grown up with it from the beginning. However large an organism may get to be, however many different kinds of organs or tissues it comes to have, it continues to be *one.*

Unifying Processes[1] Ordinarily, we raise questions about the wholeness of an organism only when parts of the body fail to work harmoniously

[1]See No. 1, p. 337.

together. We see mutilated animals, as well as plants, carry on instead of being killed by the injuries they have received. Sometimes in ourselves joints stiffen, vision dims, muscles are less prompt or less effective than we should like. The more complex an organism is, the more likely is some part to get out of step. But what is it that maintains the harmony when nothing is out of order?

We have seen that homeostasis, or the constancy of the blood, is maintained by continuous and delicate adjustments to slight changes in the temperature and chemical condition of the blood. The tropic movements of plants also result from chemical responses to changes in temperature, illumination, pressure, and so on. Among simple animals too, many of the tropic movements seem to come from chemical responses to stimuli, whether these are originally electrical or mechanical, whether they are changes in light or in temperature. In the most complex organisms, the warm-blooded birds and mammals, the blood acts as a unifying medium, for it rapidly distributes the chemical "messengers", or hormones, which the endocrine glands release under various circumstances. These hormones stimulate various parts of the body or retard their action in various ways. On the whole, however, the net effect is to bring the behavior of the entire system into harmony. That is, the endocrines harmonize the parts of the body in relation to one another, while the body as a whole acts—in most cases—with relation to existing conditions.

In addition to the chemical processes which have the effect of unifying the parts of the body, the nervous system does the same thing. In one-celled animals it is possible to locate surface spots that are exceptionally sensitive to stimuli, and also strands of protoplasm through which stimuli appear to be transmitted. We may think of the sense organs and the nerves of many-celled animals as elaborations of such areas. The sensitive spot comes to be one of several special sense organs. The sensitive strand appears as a nerve cell. There are simple nerve paths in animals connecting receptor directly with effector. There are reflex arcs, and chains or groupings of reflex arcs. In the backboned animals the central nervous system, with the brain and the autonomic nerves, ties together the sensory and muscle systems with the visceral and endocrine systems. We may say that as the one-celled animal behaves as a unity because it is all one, a many-celled bird or mammal behaves as a unity because it is in all its parts firmly bound together by chemical and nervous strands; it is hardly possible to touch a point without affecting all parts, directly or indirectly.

Instead of asking how the parts of a plant or animal do work together, it might be more helpful to think of the organism as a distinct kind of unity; or we might ask how this unity comes to have so many distinct kinds of parts, or even why the parts sometimes fail to work together.

Health and Sickness Perhaps no organism long remains perfectly adapted to the conditions around it, capable at all times of meeting every situation suitably. Perhaps no organism is immediately killed when some one part fails to act just right. Among human beings, as among other species, there are defective individuals. Some are born with imperfect organs, and all acquire various disabilities as they go along. We can imagine "perfection", but we need neither expect to find it nor give up because it does not appear in our lives. We may be sure, at any rate, that various forms of general or partial incapacity, various forms of sickness and deficiency, have troubled human beings from earliest times.

In nearly every language the most common greetings refer to health. "How are you?" We do not stop to answer each time, or we should not get on with our business. "Hail!" is apparently a shortening of "Be hail" (or "hale")—that is, Be whole, or be well. "Farewell!" is a parting wish for one's welfare, including health. The Latin *ave* and *vale* have similar meanings. The very word *salute*, from the Latin *salus*, means "health".

As a rule, we think of illness as a condition in which something in the body—that is, some part—goes wrong, and we often speak of illness or ailing in relation to some part, such as the stomach, the liver, or the knee. We seldom think of the whole organism as being sick. The trouble consists in a disturbance of the wholeness. In the course of ages many different ideas or theories have been used to explain such interferences with harmonious workings of the organism. Such theories are always important, since they guide us in restoring sick persons to health, or wholeness.

Evil Spirits One of the earliest ideas for explaining sickness is that of "evil spirits". Today we consider such explanations "superstitious" because they rest on suppositions which do not agree with known facts. Without such facts, however, most superstitions are quite as logical as our own wiser notions. We know, for example, that a scratch or a bite may cause pain. A cut may disable a hand; a sprain may disable a whole limb. We can see a stick strike and cause injury. It is reasonable to explain inner aches and pains as if they were caused by unseen sticks and stones in unseen hands—by spirits, in short. And naturally they must be evil spirits, imps or devils, for they cause evil.

To this day millions of people can understand their inner troubles only by assuming that evil spirits somehow get in and cause mischief. To be sure, we cannot "prove" that evil spirits cause troubles, for spirits are naturally beyond the reach of our senses. We know only the effects they produce. On the other hand, we can never prove that evil spirits do not cause sickness, for we cannot prove a negative. If we assume that evil spirits, or devils,

In the Louvre in Paris there is a statue from ancient Chaldea representing the demon of the Southwest Wind. The inscription directs that it be hung in a window or doorway to ward off illness and evil influences

After Lenormant

SPIRITS CAUSE ILLNESS

cause illness by getting into the victim's body, what is more reasonable than to try to drive them out of the body?

Driving Out Spirits Through the ages there have been many systems for driving out these unwelcome visitors by making it as uncomfortable for them as possible. Loud and hideous sounds, nasty odors produced by burning various substances, very bitter and nauseous mixtures—to be taken internally by the patient, of course. Sometimes a medicine man utters magic words to frighten devils. Or he writes them on bits of bark or shell, which he applies to the body of the patient. These magic words probably work just as effectively as the loud sounds and the disagreeable odors and drugs. At any rate, that was the basic philosophy of sickness and cure through many centuries. It is still the basic philosophy among many tribes in many parts of the world. It persists essentially unchanged among many of our present-day fellow citizens. We have astrologers and quacks and spirit healers in nearly every community. This spirit theory has the merit of appealing to common sense. It has the disadvantage that we are unable to compare the results of spirit activity with the workings of different kinds of cures. We have no way of checking up on the workings of this philosophy.

Sickness and Sin A child early learns that he is made to suffer if he displeases his elders, or if he fails to do as he is told. From this experience

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Tenskwatawa, the Indian prophet, healed the sick and kept evil spirits away from his people with his medicine fire and his sacred beans. We can imagine common objects having qualities besides those we discover through our senses. A gift from a beloved person, for example, or a trophy may do to us what a duplicate bought in the market could not do. But are these magical qualities in the objects or in the persons who feel and imagine and believe? And do people really believe in such magic? We have only to ask ourselves why it is that one flag, one statue, one building, arouses in us a particular set of feelings — but not in other people. Or why another flag or picture or house arouses in us quite different feelings. Does something come into us out of those stones or does something stir within?

MAGIC PARAPHERNALIA

it is but a short step to the idea that suffering or pain results from offending some unseen power or spirit. If you eat forbidden fruit, you will suffer. If you violate a taboo—for example, if you drink from a sacred spring or cross an imaginary line that you should not cross—you will be made to suffer. This idea is like the invading-spirit theory of sickness, except that it attempts to explain why the spirit or spirits should choose a particular victim. Sickness is thus considered the wages of sin.

The theory appears reasonable—if we grant the assumptions. According to this view, a sick person needs first to find out what sin he has committed and then to make his peace with the tormenting gods or spirits. Millions of people with all kinds of backgrounds and with many different kinds of religious views look at sickness in very much this way, even where an illness clearly follows a physical injury or a fall.

We find, however, that eating forbidden food and performing forbidden acts bring evil results among some parts of the human race, but not among others. We find also that some sicknesses, like rain, strike good people and wicked people without discrimination. Of course we can save our theory by saying that "good people" who are smitten only *seem* to be good—that they are really being punished for their secret sins. Obviously that kind of argument does not get us very far. Like the spirit theory of sickness, it does not let itself be checked.

Truth in Falsehood Strange as these and other old notions appear to us today, it is not fair to laugh at them. For one thing, what people with queer notions think seems to them just as reasonable as our thoughts do to us. For another thing, we have ourselves at some time held views sincerely and very earnestly only to abandon them later. But most important is the possibility that there is at least a small grain of truth in queer notions. For example, one could say that the notion that evil spirits cause disease is true if we only substitute *microbes* for spirits, although these "spirits" cannot be driven out by beating drums, or burning incense, or eating bitter herbs. Again, though we reject the "humors" of the ancients, we know that the hormones have important bearings upon health; but we do not remedy an imbalance of these juices by the methods employed by the ancients.

"COME TO THE EGG. COME, LITTLE PAINS, INTO THE EGG," SAID TRINI[1]

There are witch-doctors and magic healers in nearly every community. The magic ideas have the advantage of appealing to "common sense", so that the patient has confidence in the healer. Certainly these ideas cannot be disproved. They have the disadvantage that they cannot be tested in a scientific way nor made to serve people generally

[1]From *The Forgotten Village*, by John Steinbeck, © 1941, by permission of The Viking Press, Inc., New York.

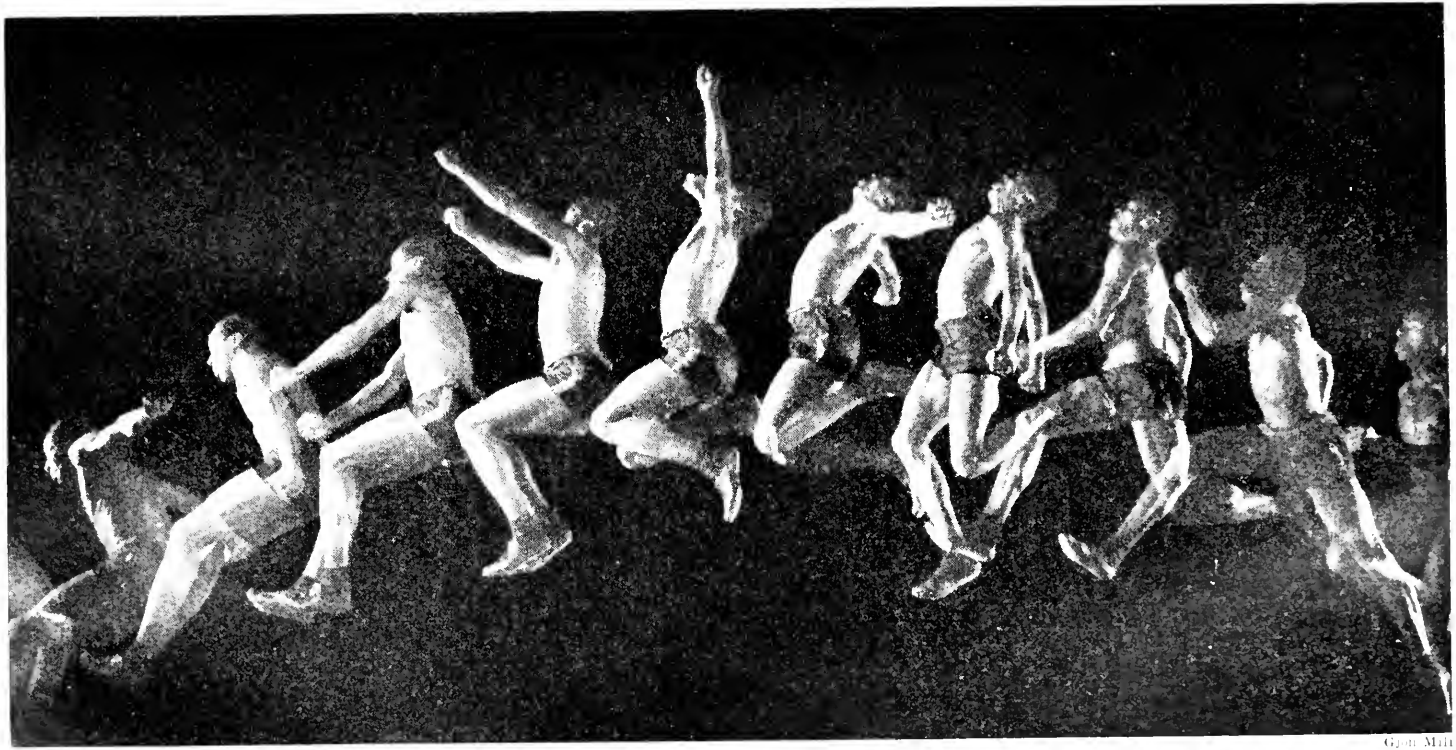
In one conception of illness, evil spirits correspond to ideas or thoughts rather than to devils. Thus many people believe that the body may be disordered by "evil thoughts", either those of the victim himself or those of some wicked enemy. This kind of belief is hard to deal with, since we cannot experiment with it. It would be very hard to prove, for example, that my toothache was *not* caused by somebody's throwing toothache-thoughts at me while I was asleep—and equally hard to prove that it *was*. Nevertheless the health of the body and the health of the mind are closely connected.

How Does the Mind Affect Health?

Physical Basis of Mental Disturbances Most of us cannot keep our minds on our work when we have any kind of pain, whether it is a slight bruise or a jumping toothache. When the liver is out of order, it is almost impossible to maintain a cheerful mood; we have the blues, or we are grouchy or irritable. Under the influence of alcohol or other drugs, men have committed acts of folly and of violence. When one is exhausted from hunger or fatigue, not only does the mind work poorly, but there may be even uncontrolled images or wild thinking. The chemical condition of the blood affects not only the rate of breathing and the digestive processes, but also the brain and mental processes. People have become insane and irresponsible from the poisoning of the blood by physical disease or by alterations in the relative quantities of the hormones. We must recognize that the mind is influenced by the physical conditions of the body.

Effects of Ideas on Organic Processes But the opposite may be just as true. One who is very much excited by good news or bad news is likely to suffer from indigestion. A person who worries is likely to become run-down physically. A cheerful frame of mind keeps up the action of the blood. A hopeful disposition helps a sick person become well more rapidly. In some mental disturbances or insanities the bowels fail to carry on their work, or the breathing becomes impaired. The physical condition of the body can influence one's dreams; but dreams or the reading of stories may affect the condition of the body so as to make one shake with laughter or shiver with cold. Instead of saying that *all* disorders are due to physical causes or that *all* are due to mental causes, we may find it more helpful to think of the body as a living organism, a unity, or whole, in which every happening may influence every part.

Mental Health and Mental Healing If we think of the organism as a unity, we shall find it easier to understand "health" as very largely a style, or mode, of life, and the state of mind as an important phase of that style, or "habit". This does not mean, of course, that all illness can be prevented by proper training, or that health can be assured by merely getting certain



Gjon Mili

STOBOSCOPE PHOTOGRAPH OF BORICAN MAKING A BROAD JUMP

The organism in action is constantly changing its position in relation to the environment, or in relation to some particular goal. In addition, all the parts of the body are constantly changing their positions in relation to one another in ways that keep the whole organism acting as one. You could not possibly think of what you would want each muscle to do, step by step, in order to achieve your purpose!

ideas into our minds. It means only that the entire organism keeps whole or well—or not. If anything goes wrong, it is important to find out what causes the trouble. But no one medicine or one trick can cure all disorders, just as there can be no one answer to all questions. We must guard against the idea that somebody has found a universal remedy, whether it is a kind of drug or a kind of exercise or a kind of lucky stone or a kind of happy thought.

How the Mind Unifies the Organism[1] At any given moment the different processes of the body are unified by the chief activity. If you are playing a game, such as basketball or tennis, the heart and the lungs and the perspiration glands and the liver and the kidneys are adjusting their activities to the body's purposes. The whole organism is on the alert. Your senses and your muscles are all *set*, in readiness for whatever your adversaries and partners may do, for whatever move the ball may make. You may become quite excited in the game, and everybody knows that excitement may work in opposite ways. If you are not warmed up or excited enough, if you do not care enough, you will not see enough of what goes on to guide your movements; you will not hit hard enough. You will not be quick enough with your responses. On the other hand, if you are too excited, if you begin to think about the score or possible failure, if you begin to wonder whether certain eyes are watching you, you may spoil the game by playing too wildly. In any case, the body works as a whole just so far as it is controlled by a single purpose or desire, and in proportion to the strength of the purpose (see illustration, p. 331).

Concentration, orderliness and perseverance make for unity and strength. On the other hand, mind-wandering and day-dreaming, indecision and worry, suspicion and jealousy, concealment and shyness, indicate a lack of unity or wholeness. At the same time, they interfere with the satisfactory co-operation of all the powers of the body in achieving a goal. A strong will may mean holding firmly and with clear vision to a definite purpose.

Attitudes The word *attitude* commonly refers to the "point of view", or position, that one takes in relation to the environment. This is illustrated by the close connection we expect between the physical posture and the state of mind in such cases as fear, defiance, curiosity and shame. Indeed, you can hardly pronounce these words and think of their meanings without having different muscles actually pull toward getting your face and arms and legs and back into positions corresponding with these various feelings. We have seen that the emotions are closely connected with all the important functions and processes of the body (see pages 308-318).

Some emotions—hunger, fear, love, anger, curiosity—sometimes drive us to do things that we should otherwise not do at all. Our impulses to action

[1]See No. 2, p. 337.

Karsten Stapelfeldt

ATTITUDES

The muscles of the face contract or relax, altering the expression in ways that correspond to every change in the emotions. But muscles in all parts of the body also respond to the feelings, even to our thought about such feelings as fear, anger, aversion, shame. Even if you cannot tell what a person is thinking from the expression on his face, you can often know what he "has on his mind" from the physical posture, which is closely related to the "mental attitude"

are modified by experience so that emotions become associated with certain actions. We then refrain from doing what we otherwise feel impelled to do. For example, fear, shame, and the desire to please certain people prevent us from doing certain things and teach us to regard them as wrong or improper. Or the same emotions push us to do things that would otherwise be too difficult.

Our emotions may be aroused by a great variety of situations, and they may in turn bring about a great variety of changes in the body. Anger, for example, may be aroused by an unfriendly act or by striking an obstruction or by seeing a bully abuse a child or by *thinking* about the abuse of power by high officials. This feeling of anger may, in turn, bring about various changes in the expression of one's face and the clenching of one's fists, involving skeletal, or striped muscles. It may cause a sudden flow of blood to the head and increased heartbeat, involving involuntary muscles. It may

stop the flow of gastric juice, make the breath come stronger, and bring about other changes in various organs.

The manner in which we allow various happenings to stir our feelings, and the manner in which we allow our feelings to find their way out in action, both depend largely upon experience. *They* are "learned" rather than "natural". These feelings we have of liking or disliking, of being for or against anything, are our attitudes.

What Is Mind? We intend many of the things we do; that is, we can give a reason for doing them. Thus we drink because we are thirsty; we do other things because they help us carry on our lives. But many of the things which the bird or the ant does also help it carry on life. We are therefore disposed to say that the animal does things on purpose just as we do, or that the unity of the organism is due to the "mind" in one case as in the other.

It would be quite impossible to prove that this interpretation of the facts is not a true one. For all we know, it is the "mind" of the insect or of the bird or of the morning-glory that makes it behave as it does. But if it is a mind, it is a different kind of mind from ours. For, as we have seen (see pages 255–264), a great deal of the behavior in plants and animals at all stages of development is automatic; it comes from the structures or from the chemical compounds in the organs, rather than from any intention or purpose.

When we speak of our own minds or of doing things with design, or purpose, we do not include all our actions, not even all the useful ones. In the course of the individual's development, for example, the thymus gland gradually degenerates. However useful this change may be, none of us would maintain that the gland degenerates as the result of any design on our part. As the body does more work, and as the tissue cells give off more carbon dioxide, the heart comes to beat harder. Yet it is doubtful whether anybody ever *intended* to have his heart work harder. Certainly no one ever planned to grow himself a heart in the first place, useful as that organ happens to be.

What we do intentionally or willingly, whether wise or foolish, can hardly come from the same "mind" as that which guides the growth of the body and its unconscious internal and external adjustments to what is happening. On the other hand, we really know only such mind as our own, and that mind does play an important role in our own adjustments. But we recognize degrees of mind in other species, even if we can also see a great deal of adaptive response that is mechanical or automatic.

Irregularities in Development It seems logical to distinguish from the external sources of harm possible internal sources. But these are not so easy to recognize or to classify. We have learned a great deal about *spontaneous* disturbances in metabolism, but that idea is a hard notion to deal with scientifically. For to say "spontaneous" is really to say that we *do not know* how such disturbances arise. The endocrine system may be thrown out of balance, for example, by faulty nutrition, as by a deficiency of iodine or of calcium. Generally speaking, however, most cases of hormone imbalance do not seem to arise in that manner.

Individual differences in development not only bring about obvious changes in the *proportions* of the various organs, they bring about also obscure changes in the workings of different organs. Thus, as one grows older, a change in the shape of the eye lens may make one more and more farsighted. A change in body weight may put an increasing burden upon the heart. Other changes may alter the quantities of various hormones produced; for example, diabetes may appear "normally" in some individuals past a certain age as a part of the developmental changes.

Disturbed metabolism shows itself in growths that have no adaptive value to the organism (as certain kinds of tumors) or that may be destructive (as in the case of cancer). Some of these abnormal growths are no doubt due to local irritation or to some chemical disturbance from the outside. We are unable, however, to find a universal formula for these diseases or for diseases in general.

Ways of Living The mode of life influences the internal adjustments and may bring about an organic imbalance even if no specific cause can be found for illness.

Many of the inner processes are affected by our "habits"—exercise, work, rest, recreation, posture—and states of mind. That is to say, fatigue and circulation, breathing and excretion, anxieties and worries, excessive eagerness or fear, exaggerated emotional activity, are so closely associated with endocrine disturbances that it is often difficult to say which is the cause and which the effect. Much dyspepsia or heart disease, for example, may mean not any specific defect in stomach or heart structure, but faulty workings of organs in response to high-pressure living or to constant anxiety. Thus physicians distinguish between *organic* and *functional* disorders. They emphasize the idea that aches and pains and difficulties indicate a disturbance of the organism's unity, or wholeness, but not necessarily the cause of the disturbance. This is a practical distinction in medical treatment, for it means that we are to remove the sources or causes of a patient's disunity rather than merely get rid of the symptoms.

In Brief

A living being acts as a unit, or whole, not as a mere collection of parts.

Specialized cells or tissues may be grown in the laboratory; in a culture they are able to grow and multiply, but they are not able to supply themselves with food, air, or water. They can continue to live only so long as their needs are met by laboratory attendants.

We cannot understand the parts of a human body, or of the body of any other living thing, except in terms of the whole living organism, in which every happening may influence every part.

In the larger plants and animals, the complete unity of an organism is observable in its every action, at every stage in its development.

As differentiation of parts occurs in the development of an animal, different cells act in somewhat different ways; yet the whole mass of cells behaves as one organism.

Some of the functions or activities of specialized cells are more general than others; thus an organism can continue to live if certain parts are destroyed, but not if other parts are destroyed.

The more elaborate and specialized an organism is, the more of its body consists of specialized accessory organs and tissues, and the more of it consists of nonliving structures.

Throughout the ages there have arisen various beliefs and explanations for sickness which later generations ridiculed as foolish. But we are unable to prove or disprove these beliefs, as each involves, to some extent, reliance on supernatural beings or forces, with which we cannot experiment.

Illness results when the unity of an organism and the effectiveness of its adjustments are thrown out of balance by any of a variety of events.

The chemical condition of the body fluids influences mental processes, as well as others.

Various habits of feeling and thinking and acting influence the internal adjustments of the body and may bring about an organic imbalance.

The body works as a whole so far as it is controlled by a single purpose or desire.

We distinguish as work of the "mind" that control which is purposive, or conscious, or voluntary, in contrast to that unconscious control which automatically adjusts the body both to internal and to external changes.

EXPLORATIONS AND PROJECTS

1 Take a field trip to observe bird behavior. In a region in which birds abound, locate some species feeding. Note its activities to see its relations to the character of the food. Or observe parent birds feeding their young. In what ways are the various activities of the birds tied together?

2 To observe the wholeness of response in a young child, have someone volunteer to bring a baby brother or sister for the rest to watch. Take every precaution to protect the child against the possibility of frightening. Everything in the situation is new. Normal behavior cannot be observed unless each one in the group is extremely co-operative. Note any evidence that the child responds to various stimuli—the people in the room, the strange surroundings, the known brother or sister, or to such things as light, sound, heat, contact, odor. Touch lightly the sole of the child's foot, the palm of the hand, the cheek near the mouth, or touch the child under the chin. Note whether any stimulus seems to hold the child's attention, whether he follows a moving object or a sound, whether he responds to an approaching object. Observe every movement; note any associated responses in other parts of the body. How does the child explore the new environment?

In what sense may the activities of the child be considered as simple responses to stimulation? In what sense may the activities be considered as expressions of a single being, or a unity?

QUESTIONS

1 In what respects does a one-celled organism act as a whole?

2 In what respects is the unity of a mature complex organism like that of a single-celled organism? In what respects is it unlike that of a single-celled organism?

3 In what sense does the presence of specialized organs indicate the complete unity of a living organism?

4 How do various injuries or diseases affect the unity of the organism?

5 In what ways can physical conditions influence mental processes?

6 In what ways can mental processes influence physical processes?

7 What, if any, physical processes in the body have no influence whatever upon the mind?

8 What, if any, mental processes have no connection whatever with physical changes? How can you tell?

9 What connections are there between health and emotions?

10 What kinds of physical habits keep one well? What kinds of mental habits keep one well? What kinds of emotional habits keep one well?

11 How is it possible to be happy without complete health? How is it possible to be of great use to others without complete health?

Students of biology are in somewhat the same predicament as boys who take clocks or cameras apart and are scolded for being "destructive". Our defense, which is reasonable enough, is that we want to find out how a thing works. But then we are challenged (1) to put the parts together again, which is not always very difficult, and (2) to make the machine work again, which is often impossible.

Biologists have sorted out over a million distinct kinds of plants, a million distinct kinds of animals. They have anatomized or analyzed animals and plants into many kinds of organs and tissues. They have analyzed organisms chemically into many kinds of compounds, and they have listed the elements found in all organisms, as well as elements and compounds found only in certain special kinds. When we try to put the pieces together again, we are baffled.

Biologists have analyzed the conditions under which various plants and animals live—light, temperature, water, chemical substances, and so on; and they have studied the changes in living things which result from alterations in these conditions. We can take a plant or a bird away from its natural surroundings and study it in the laboratory, but we cannot keep anything alive *apart from the environment*. Organism and environment are inseparable, except in our thought about them.

We can measure pulse rates, blood pressures, oxygen exchanges and nerve impulses. Yet none of these things *exists*—as a living process—when separated from the others. We know a great deal about muscles. But muscles have meaning in "life" only in relation to other muscles, in connection with nerves, in exact timing with blood flow or heart action or with chemical changes in remoter parts of the body. However much we find out about each part, we can recognize life only as a unified interaction of many processes, involving all the parts. In the ameba and other one-celled organisms we say that the protoplasm is alive. The single cell carries on all the life functions—feeding and assimilation, breathing and oxidation, movement, excretion, sensation, reproduction. A lobster or a fish performs various necessary functions through various organs. This fact of having special organs related to special functions has been called *the physiological division of labor*.

In higher animals division of labor appears gradually during development. This means that digestion goes on in a living thing before it has any digesting organs; breathing goes on before it has any gills or lungs; excretion goes on before it has any kidneys. This idea may be easier to grasp if we recall that in the evolution of society clothes were made long

before there were any tailors, food was prepared before there were any cooks, and so on. We summarize this idea by saying that "function precedes structure." Protoplasm is able, then, to grow the special organs, as well as to perform the various functions.

In spite of the many kinds of organs that we find in the human body and other complex species, *the organism always acts as a whole.* The various functions, however different they may appear, are all *functions of protoplasm.* It is this unity of the organism that makes life both significant and interesting; the more complex the organism, the more varied its parts, the more wonderful is the total life in variety and interest.

Of course the human body does not come from joining together millions of cells that were once distinct. Like other organisms, it develops from a single cell that divides into two cells, each of which again divides, and so on until millions are formed. The many different kinds of cells and the many different organs appear gradually by a process of *differentiation*, and the different tissues and organs gradually take on *specializations* in their functions. The organism has been a unity from the first. It is only because we have taken the body apart *in our studies* that we must ask ourselves how the parts are kept working together. It may be more helpful to ask, How comes a bit of protoplasm to take on such complex forms and grow itself into so many specialized organs?

The various organs or systems do work together because they are, so to say, continuous with one another. They make up, essentially, a unit of protoplasm, confronting the world in all directions as one, in spite of the many specialized parts. All cells are connected through the blood, which distributes nutrients and oxygen and which removes the products of metabolism. All the body cells are sensitive to the slightest changes in the chemical state of the blood, and they all bring about changes in the blood. Operating through the blood are the hormones, which are sensitive not alone to the chemical state of the blood, but to more specialized stimulations by way of the nerves. In turn they act upon the entire protoplasm—counteracting, compensating, reinforcing.

Finally, the irritability of protoplasm manifests itself, in the more complex animals, by the formation of the *nervous system.* This reaches all parts of the body; and it is sensitive to changes inside, as well as to the changes and disturbances in the environment. The nerves are connected not merely with the muscles and the organs of special sensation (eye, ear, tongue, and so on), but also with the blood-vessels and with the ductless glands. Because of their extreme sensitiveness and their quick response, they constitute a very striking system of co-ordination, or unification, in the body.

In the behavior of every plant and every animal we are impressed by the *fitness* of the actions and of the chemical processes. Plant and animal action

often suggests what we would ourselves do under similar circumstances, so that the behavior appears purposeful. We know that we are able to select lines of conduct that do not come spontaneously. By so choosing, we obtain from the world many advantages that we should not otherwise have; or we escape many dangers or inconveniences to which we should otherwise be exposed. We have a certain control both over the workings of our bodies and over our environment. Or, rather, *we have a certain control over our environment by means of the control which we have over our own actions.* This control of our own activities comes by way of the most elaborate part of the nervous system, the brain. Nevertheless we cannot say that plants and simple animals act with design, or purpose, no matter how useful the processes are.

For one thing, we can reproduce the parts of many of these processes by means of physical and chemical mechanisms. For another thing, *purpose* means nothing unless we assume the presence of a mind like our own, *which can think of the future*; and from what we know of these organisms we cannot asume that they have such a mind. Indeed, most of our own acts can be shown to be without purpose, even where they are of value to the organism. It therefore makes no sense to attribute purpose to organisms of whose "minds" we know nothing. What they do, like most of what we do, comes from being the kinds of organisms they are; they cannot help it. The wonder still remains: "How come?"

UNIT FIVE

How Do Living Things Originate?

1 How do different kinds of plants and animals live through the winter?
2 Does a seed or egg contain a miniature of the parent?
3 How does a worm change into a butterfly?
4 How do animals without eggs reproduce themselves?
5 How does the egg change into a complete animal?
6 What is the difference between growing and developing?
7 What becomes of all the seeds in nature that do not grow into plants?
8 Is there sex in all kinds of animals?
9 Why are the young of some species helpless at birth, whereas those of other species are not?

Everybody knows that chickens hatch from eggs and that kittens come from mother cats. Everybody knows that weeds, garden truck, and farm crops come from seeds. Such familiar facts receive very little thought from most of us. From earliest times, however, people commonly believed that plants and animals whose seeds or eggs were not generally known arose spontaneously, that is, of themselves. The sun acting on mud might produce frogs, for example; a piece of meat or cheese allowed to rot soon swarms with wormlike maggots.

From the time of Aristotle down to less than a hundred years ago, well-informed and intelligent men still assumed that fleas and mosquitoes and many other living things arose spontaneously from decaying matter. They accounted in this way for worms found in the intestines of man and other vertebrates, and even for rats and mice. In the sixteen-hundreds an Italian scholar and physician, Francesco Redi (about 1626–1697), attacked the problem by the method with which his countryman Galileo Galilei had startled the world; that is, he used the method of experiment. Instead of arguing, he said "Let's try it."

Redi placed fresh meat in several jars. He left some of the jars open. He covered others with thin cloth, and still others with parchment. In all the jars the meat began to decay. In the open jars the meat became wormy, but *not in the covered jars.* On the other hand, the cloth covers had on them the eggs of flies. Redi established the fact that maggots come from the eggs of flies. Yet he continued to believe that other forms of life do develop spontaneously. Two hundred years later a French chemist, Louis Pasteur (1822–1895), and an English physicist, John Tyndall (1820–1893), showed by experiments that even the rotting of materials is due to the action of

"microbes", that is, small living things; and that the microscopic organisms which bring about decay arise in each case from others like themselves.

Every single plant and every animal about which we have positive information has come from another organism of the same kind. Yet that all life comes from life is one of those big ideas which we can never prove in an absolute sense. Our knowledge is limited to what we have been able to observe. In our general statements we reach out to other objects and events *of the same kind.* In thus reaching out, we rely upon two important *assumptions*: (1) We assume that things "of the same kind" are the same in origin, structure, qualities, behavior, and so on. (2) We assume that we can recognize things "of the same kind" when we come across them, without always stopping to ask in exactly what ways and to exactly what extent they are really "the same".

Among so many different kinds of living things, it is conceivable that they originated in different ways. Moreover, in our constant efforts to find general rules or general ideas, we cannot help wondering what connections there are between the various processes or events and the beginnings of new individuals. What connection is there between modes of reproduction and the conditions under which different species live? Are the methods the same among plants as among animals? among land forms and water forms? Is there any connection between the length of life and the methods of reproduction? And why is it that some species produce very many eggs or seeds, or many new individuals, whereas other species produce only one or a very few offspring at one time?

Questions about the origin of new individuals may come in many cases from idle curiosity. Yet answers often have important practical bearings. It is important for us to produce large numbers of some kinds of plants and animals, and it is important for us also to check the multiplication of others.

1. What makes a plant or animal stop growing?
2. Is there anything besides feeding that makes the members of a species differ in size or development?
3. Is there any advantage in being larger or smaller than the average?
4. Can anything be done to quicken growth or to slow it?
5. Does every part of the body need exercise in order to develop?
6. Why do people grow faster at some times than at others?
7. Why do some parts of the body grow faster than others?
8. Do any new organs develop after one is born?
9. Can a part that has stopped growing be made to start growing again?
10. Do people become more alike or less alike as they grow older?

Most of the people you know have grown in the last year or two. Nearly everybody, but not quite all. For in addition to the universal fact that living beings grow is a second general fact, namely, that they stop growing. Moreover, the parts of a plant or animal grow at different rates, so that shapes, forms or proportions change.

In some species of plants, like the famous redwood trees of California, the individual may keep on growing for centuries. Some animals keep on growing as long as they remain alive, as certain fish. But in most of the familiar species the individuals reach a fairly definite limit of growth. They may then continue to live for a time, but without becoming larger. On the other hand, even after the body reaches full size, some parts may continue to grow, as do our hair and nails or the fruits on many shrubs and herbs.

Why does not the increase in size of living things continue through life? What determines the different rates of growth among different species or among the different parts of one plant or animal? How can the growth of living things be controlled?

How Do Plants and Animals Increase in Size?

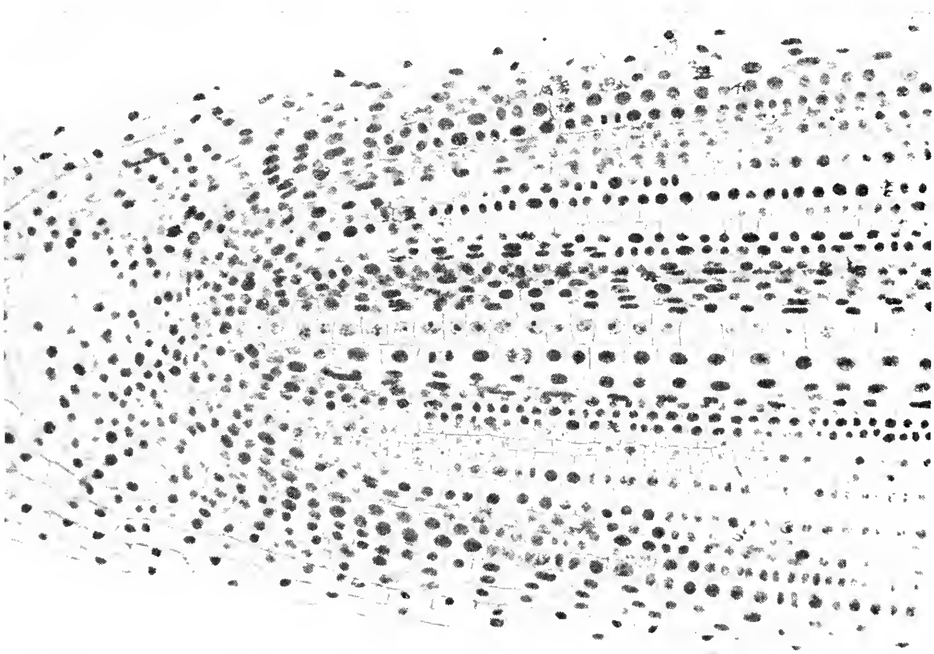
The Steps in Growth When the conditions are suitable, an organism grows by two distinct processes:

Cells enlarge as they form new protoplasm by assimilating food. This is true of one-celled organisms, as well as of many-celled organisms. A cell may indeed increase in size by absorbing a quantity of water, just as a piece of leather or wood swells when it absorbs water. But by growth we usually mean the making of more protoplasm.

In addition to producing *new protoplasm*, a growing organism produces new cells through cell-division (see illustration below). Cell-division increases the number of cells. Each new cell is, of course, smaller than the mother-cell. In one-celled as well as in many-celled organisms, cell-division increases the *number* of cells; assimilation increases the quantity of protoplasm. And in every case living is *continuous*; the new protoplasm formed is like the old protoplasm, and the new cells are like the old cells.

Sizes of Cells We have seen that as a body grows larger, the volume increases more rapidly than the surface (see illustration, p. 117). In time, therefore, the ratio of surface to volume may be too small to allow for the absorption of surplus for new protoplasm. At that point, of course, there can be no further growth (see illustration opposite).

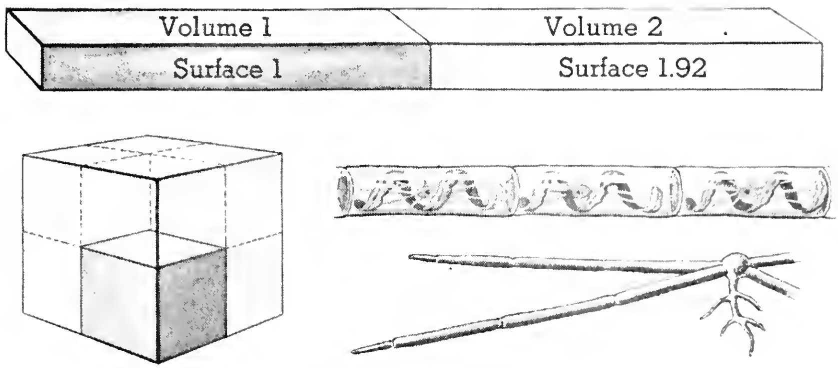
Conditions of Growth The most prominent single condition for the growth of protoplasm is a supply of food, more specifically, protein. It does not follow that a surplus of food will ensure greater growth. A Shetland pony, for example, cannot grow to the size of a draft horse by merely increasing its food intake. An excess of food may make a mouse grow to be



Region of rapid cell division　　　Region of cell growth

GROWTH BY CELL DIVISION AND ASSIMILATION IN ONION ROOT

Cell division increases the number of cells; the stained nuclei are close together. Each new cell is, of course, smaller than the mother cell was; but it grows larger by assimilating food, so that the entire structure increases in size



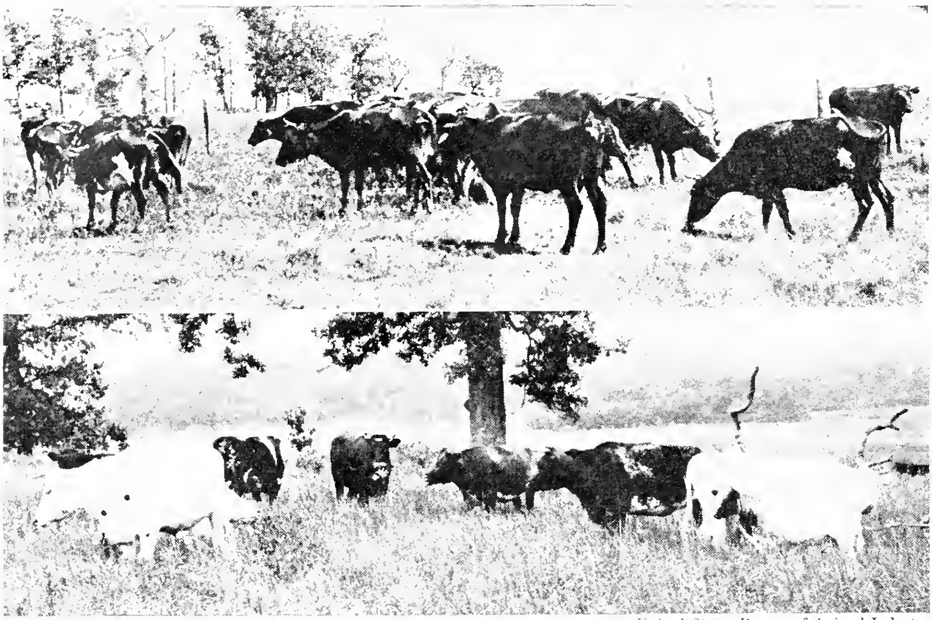
LIMITATION ON GROWTH

A cube twice as large as another has 8 times as much material in it, but only 4 times as much surface. But it would be difficult to make sure that any particular cell actually stopped growing because its volume had become too large in proportion to its surface. This purely mathematical idea is supported, however, by the fact that thread-shaped cells or series of cells, like those of certain algae and fungi, appear to grow indefinitely in length. In the growth of such structures the volume increases very little faster than the surface

larger than some of its hungry companions, but it will not make a mouse grow to the size of a rat. Conversely, insufficiency of food, though it may not kill the organism, may stunt its growth.

Size, like any other characteristic of a living thing, is influenced by the surrounding conditions. The pine tree, for example, attains its size and shape influenced in part by soil and weather; that is, it grows better in some locations or in some climates than in others, growing faster when it is warmer. The squirrel in the tree's branches is also influenced in its growth by the food it can get, by weather conditions, and perhaps by enemies. In each case, however, the organism reaches a size that is fairly characteristic of the species; that is, how fast an organism grows and how long it continues to grow are determined in part by the *kind of protoplasm* of which it consists (see illustrations, pp. 346 and 561).

Moreover, as a baby or any other living thing grows, it is constantly changing in shape, as well as in size. That means, of course, that some parts are growing faster than others, or that some parts slow up or even stop growing, while other parts keep right on. In the body of any particular individual, each cell stops growing when *it* reaches a certain size; and the cells of a particular part will stop dividing when the structure or organ reaches a certain size (see illustration, p. 347). As a consequence, our own bodies, for example, contain many different kinds of cells, of many different sizes, and in various proportions.



United States Bureau of Animal Industry

OBSTACLES TO LIVING

Two herds of cattle of the same age and the same breed were supplied with abundant food. One, however, was infested with ticks, which interfered with the nutrition and health and growth of the animals

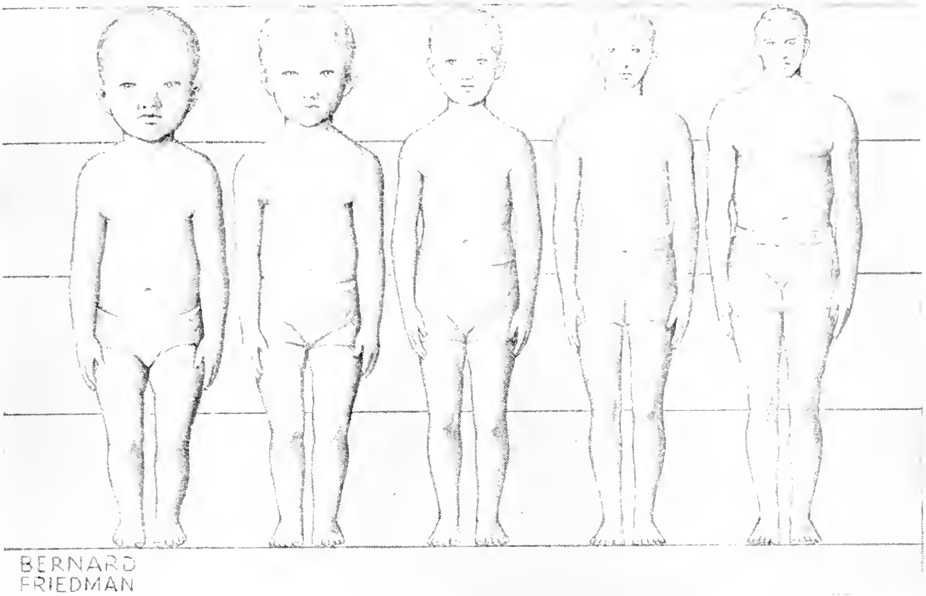
How Do Different Kinds of Cells Arise?

Variations in Protoplasm[1] The individual has grown from a single cell. This has given rise to more and more protoplasm. It has divided into more and more cells. There come to be many different parts, many different tissues, each having distinct qualities (see illustration, p. 348). How can the growing body be constantly changing and still remain the same individual?

One way of answering the question is to say that there is really no important change between the egg and the later stages; there only seems to be. That is, the chicken has always been in the egg, only too small for us to recognize. If we open a swollen bud in the spring, we can see the tiny leaves, which merely enlarge and unfold as they absorb water: nothing changes. The oak tree is already present in the acorn, and growing up is merely an expanding, an unfolding. In most seeds we can actually see the distinct parts of an entire plant—root, shoot, and leaf.

Preformation This idea that the organism exists—in miniature—in the egg and merely unfolds as it grows is a very old one and appeals to many people as quite reasonable. Through many centuries people thought that *pre-formation* was the correct explanation—that everything that the indi-

[1]See No. 1, p. 364.

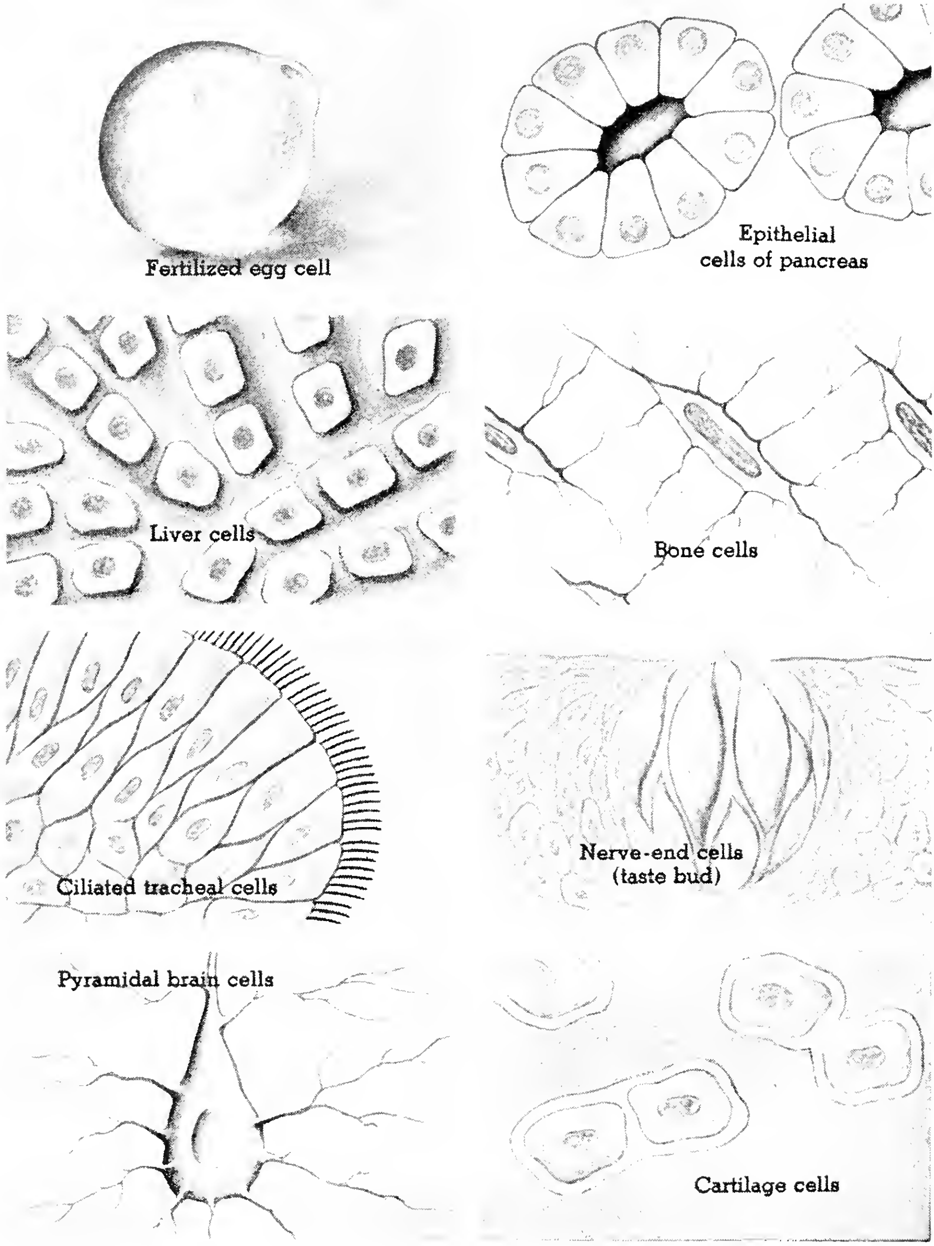


METAMORPHOSIS IN MAN

Before birth the head grows proportionately more than any other part. After birth the legs grow most and the head least. Many other changes in proportion take place in all parts of the body

vidual becomes is already formed in advance, but too small for us to see. When Leeuwenhoek and others introduced the microscope, many rushed to examine the earliest stages of various plants and animals. Some of these searchers found what they were looking for. They could see the outlines of a fish or a frog by looking through the microscope at the egg of a fish or a frog. Others could see the outlines of an animal by looking through the microscope at the sperm.

With what they had thought out in advance and what they thought they could see through the microscope, many actually drew pictures of tiny animals, and even of a tiny human form—a "homunculus", or minute human being, preformed and destined in good time to develop into a person. However reasonable this idea of preformation may seem, it raises special difficulties. It suggests, for example, that in the "homunculus" there are already present the germ cells, or "seeds", each with its own preformed individual; and that these tinier individuals in turn have inside themselves the seeds for the next generation, each with its still tinier individual, and so on to the end of time. And if that is really the case, then we should have to assume that that condition existed from the very beginning—so that, as some writer put it,



THE DIFFERENTIATION OF CELLS

In the earliest stages of an individual's development all the cells are very much alike. When there are several hundred cells, it is possible to make out layers of distinct kinds of cells. Later we can recognize different tissues, or masses of similar cells, such as skin, muscle, bone. After the distinct tissues are established, a dividing cell produces new cells like itself

the whole of the human race must have been present in Mother Eve! However, better microscopes and more thorough study have convinced most people that "preformation" does not agree with all the known facts.

Transformation Another way of answering the paradox about changing and remaining the same is to recognize that the trouble may really be with the words and not with the facts. A living thing *is* constantly changing, physically and chemically; and yet it remains the "same" individual. The only way it can continue to be the same individual is through constantly changing. The real question is, Just exactly what changes take place between being an egg and being a hen? We still have to get the facts in each particular case. Just how does an egg become transformed into a hen?

From Egg to Hen[1] Aristotle was probably the first person to try to answer the question *How does an egg become a hen?* by experimenting instead of arguing. If we place a number of eggs under a hen (or in an incubator kept at 103° F), we expect the same number of chicks to come out of the cracked shells in about three weeks. We might follow Aristotle's plan, removing the eggs one at a time and examining the contents. In a fresh egg, even before the hatching begins, we are able to see a whitish speck floating on top of the yolk—the "germ spot". Day by day this speck becomes larger. In half a day, the speck is longish. Even without a microscope we can see the beginning of structure; there is a darker line down the middle (see illustration, p. 350). We are able to see more than Aristotle saw, for he had no microscope. We can see in the changing chick within the egg what is perhaps more easily seen in the corresponding parts of simpler animals.

The Origin of Tissues[2] Eggs of frogs and of various fishes are easily kept in dishes of water at ordinary room temperature. Patient watching of these eggs reveals progress from the one-celled stage through several more or less distinct many-celled stages (see illustration, p. 351). What we see in the simpler backboned animals or in insects is similar to what we find in mammals and in other classes of animals.

In some species differences in size among the cells appear after only a few divisions. In the early stages of a frog's development the cells in the upper portion of the cell mass are much smaller than those in the lower portion, and more numerous.

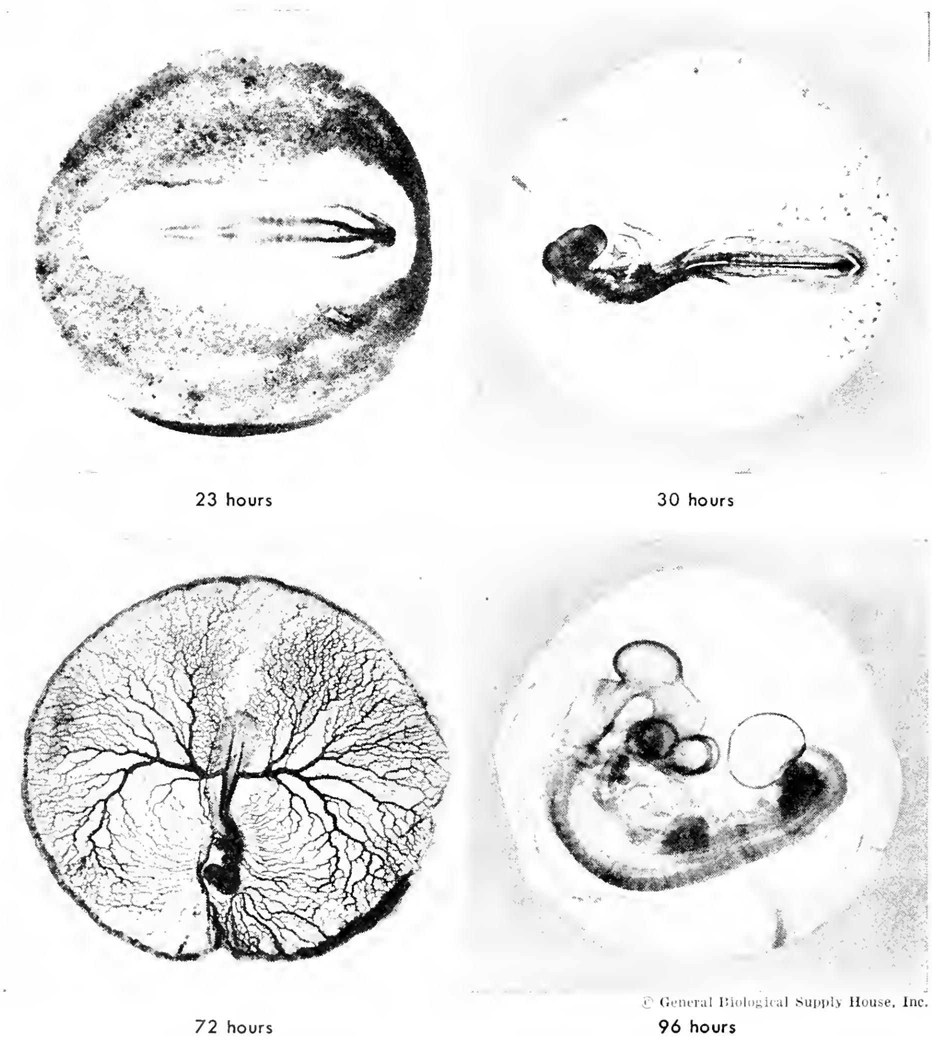
Inequalities in the rate of division and inequalities in the growth of the cells soon change the shape of the whole mass. Gradually new kinds of cells appear in the young embryo. At first these are in layers, or membranes.

The embryos of many different species consist, at one stage, of membranes with spaces, or cavities, among them. The membranes grow out irregularly into the cavities, forming folds. They break through in some

[1]See No. 2, p. 364. [2]See Nos. 3 and 4, p. 365.

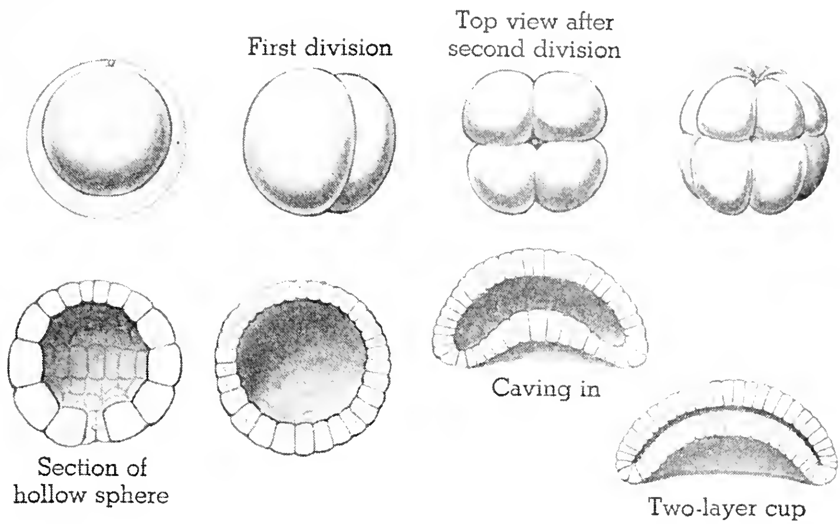
places, and they become joined in other places. In this way the three original layers—outer, inner and middle—give rise to the several kinds of tissues that make up the organs of the animal.

When a locust or a cockroach comes out of an egg, it is very much like the parent, except that it is very small and lacks wings (see illustration, p. 352). By a series of *moltings* the animal not only becomes larger but puts on wings and other organs. When the egg of a moth or of a butterfly



FOUR STAGES IN THE DEVELOPMENT OF CHICKS

While Aristotle followed the scientific method to answer the question of how an egg becomes a chick, it was impossible until comparatively modern times to see in great detail just what happens during the development



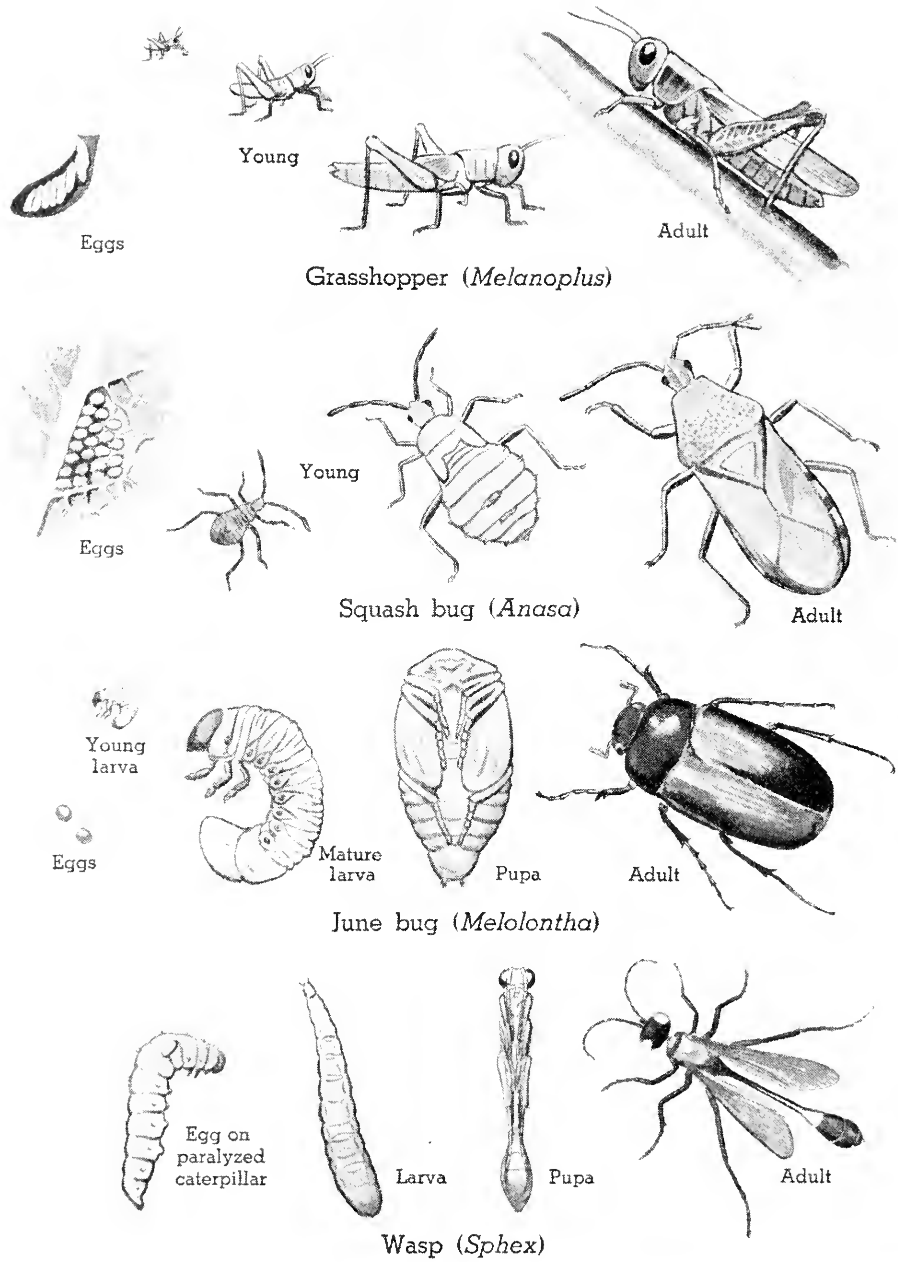
EARLY STAGES IN THE DEVELOPMENT OF A FROG

The yolk material is heavier than the protoplasm and remains at the bottom of the mass. When a cell division takes place in a horizontal plane, the upper cells are smaller and more active, and the lower ones, with more inert food material, larger and less active. At one time the frog is a hollow sphere; at another, a two-layer cup

hatches out, the young animal looks more like a worm than like the parent. It has no wings, as has the adult. Its biting jaws work sideways. It differs from the adult so much that we should never suspect its connection with butterflies if we did not observe its origin or its later development. In the life history of frogs and salamanders there are also distinct stages, in some ways as well marked as those of the insects (see illustration, p. 355). The development of an individual through a series of well-marked stages is called a *metamorphosis*, which means "trans-formation".

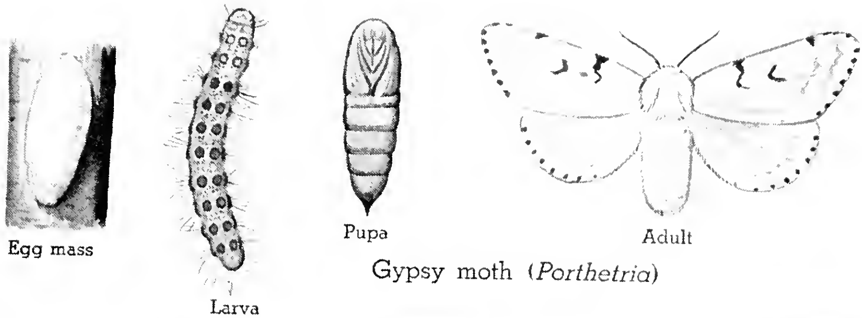
Differentiation[1] There is another way of looking at the process of development. As the mass grows and as it undergoes changes in form, the cells become more and more unlike the original cell from which their growth started. They also become more and more unlike one another. The skin and muscle cells become distinguishable from the bone and nerve cells. The cells of the stomach glands become different from those of the saliva glands. Cells come to differ from one another in size, in shape, in coloring, in texture, and in their chemical peculiarities. There is a progressive *differentiation.* Growth, differentiation, metamorphosis, are various aspects of the same general fact of *development*, which is characteristic of all living things.

[1]See Nos. 5 and 6, p. 365.

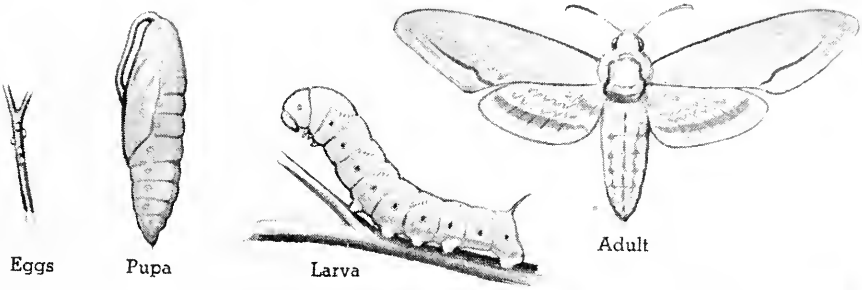


METAMORPHOSIS IN INSECTS

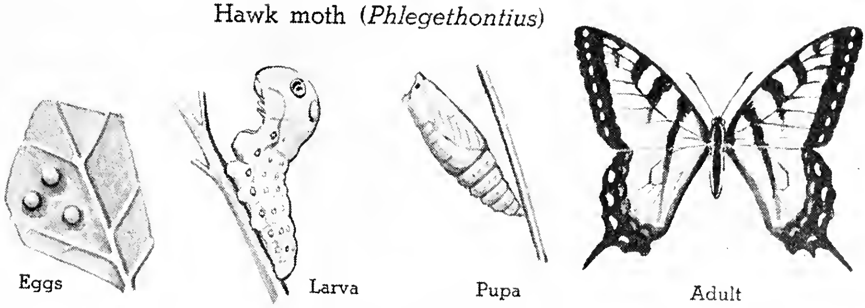
In some orders of insects, the young hatching out of the eggs resemble the adults of the species, although they lack wings. Since they have an external skeleton, they can grow only while this is still soft. After feeding awhile a young insect molts, or casts off its hard shell, and then grows rapidly until a new exoskeleton hardens



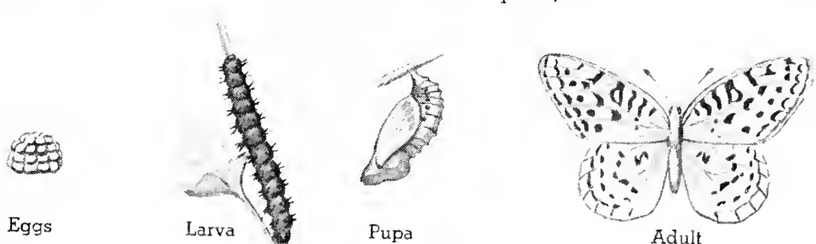
Gypsy moth (*Porthetria*)



Hawk moth (*Phlegethontius*)



Tiger swallowtail (*Papilio*)



Fritillary (*Argynnis*)

METAMORPHOSIS IN INSECTS

In some orders of insects the young resemble "worms", or grubs, rather than their parents. In later stages the individual differs in structure and in behavior from both the adult and the young, wormlike stage. Where the several stages are quite distinct, the development is called a "metamorphosis", which means a transformation

Similarities in Development At the very start, every animal is like a protozoon; it exists as a single cell. In a large number of more complex animals, like the starfish, the snail, the lancelet, there is a stage in the development that consists of a hollow sphere of cells. In the development of the frog, birds, and many other animals this hollow-sphere stage is not so clear, being obscured by the yolk. The hollow sphere caves in and the opposite sides meet, forming a two layered cup. This stage of the organism may be compared to such animals as the hydra, which never gets much farther than being a two-layered cup (see illustration, p. 274). Then the two-layered cup becomes longer, suggesting certain kinds of worms.

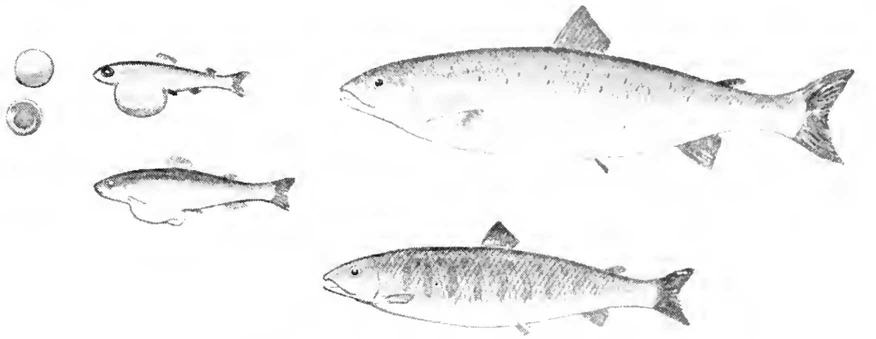
The embryos of animals that are closely related, such as several kinds of backboned animals or several kinds of insects, show still more remarkable resemblances. Thus the fish, the bird, the salamander and the rabbit continue very much alike when it is already possible to distinguish head and trunk and limbs (see illustration, p. 459). In a somewhat later stage it is not difficult to distinguish the bird from the fish or the tortoise. But at this stage there are still certain resemblances between the birds and the reptiles. Moreover, the embryos of several mammals (rabbit, pig, sheep and man, for example) are at this stage strikingly similar. As they become older, they become more and more different.

Metamorphosis in Man[1] In general form, the human infant resembles the adult. We therefore do not commonly think of metamorphosis in human beings. But if we compare the proportions of a baby with the proportions of an adult, we can see that the changes are real. But a man is something more than a large baby, something different in every detail (see illustration, p. 347).

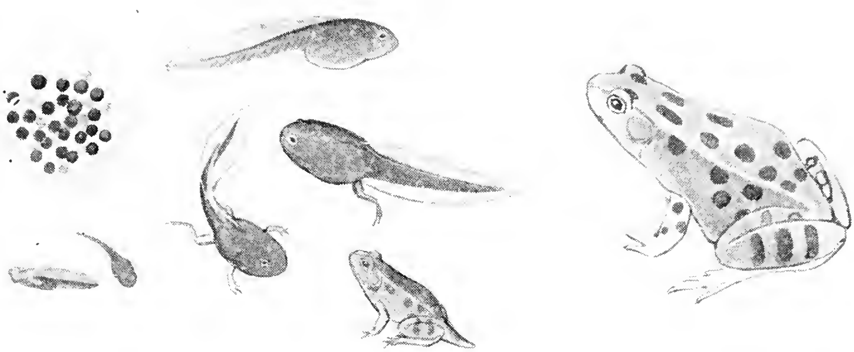
We know, of course, that as we become older many changes take place in the proportions of the various external organs, particularly of the head and face. Changes take place also in all the internal organs, in the relative sizes of the heart and lungs and liver and stomach. Some organs that are present in infancy may disappear. Others not present at one stage make their first appearance later on. Some structures which appear at first to be formless knobs or buds gradually acquire definite shapes, with distinct parts, as the body reaches maturity.

Like other animals, the individual human being develops from a single and comparatively simple cell to a very complex being made up of many different organs. The organs, as we know, consist of many different tissues, each consisting of countless cells of distinct kinds (see page 348). Through a series of cell divisions that double the number of cells at short intervals, the

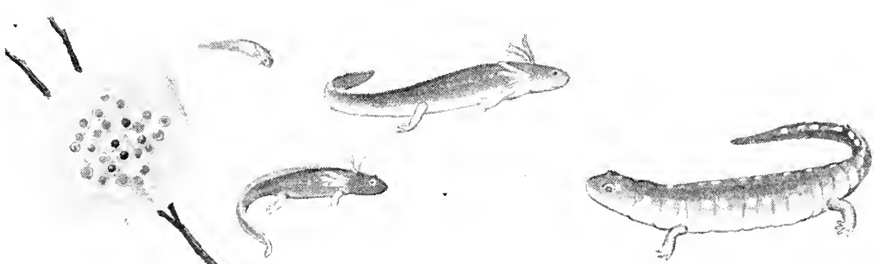
[1]See No. 7, p. 365.



Chinook salmon (*Oncorhynchus*)



Leopard frog (*Rana palustris*)



Spotted salamander
(*Ambystoma maculatum*)

METAMORPHOSIS IN VERTEBRATES

Among the vertebrates only amphibians seem to have the distinct stages making up a "metamorphosis". Among birds and mammals the transformations during the individual's development are much more complex, but they take place within the egg or within the body of the mother, so that the individual has already attained the general form distinctive of the species when he first appears as "free-living"

single cell becomes in a few days a spherical mass of many more or less similar cells.

In three weeks the mass of cells has become elongated, but hardly recognizable as any particular "kind" of animal, although it has distinct vertebrate characteristics. There are many kinds of cells. The surface, or "skin", cells differ from the internal cells. Certain layers come to be more like "muscle", and others come to be definitely digestive structures. It is possible to see little knobs of cells that correspond in position and form to prospective "bone" masses. Other lumps of cells suggest the beginnings of nerve tissue.

By the end of the fourth week there can be no doubt that the young embryo is a mammal, and not a fish or a bird. At five weeks, little buds indicate the positions of arms and legs. Later the tips of these buds begin to divide into the rudiments of fingers and toes. While the head end of the embryo has in the meantime been growing faster than other parts, we could hardly recognize the features as being especially "human" until about a month later.

Now the eyes and ears and nose and chin become steadily more distinct—and more distinctly human. By the time the baby is born, it is already a particular person. In every family those who see the young infant usually remark upon its resemblance to one or another of its various relatives. One observer sees the mother's eyes or the father's mouth. Somebody else recognizes an aunt's chin or a grandparent's forehead. In other words, that indistinguishable cell or lump of cells has come to be not only a human being but a unique human being, a distinct combination of organs and features and tissues and chemical characteristics that is different from any other living combination. And at the same time, not only does this human being consist of the "same" kinds of organs and tissues and processes as other human beings and other mammals, but it has passed through the "same" distinct stages of development as other backboned organisms (see illustration, p. 459).

Recapitulation The foundations for the scientific study of embryology were laid by Karl Ernst von Baer (1792–1876), who was born of German parents in Estonia, but was educated in Germany, where he did most of his work, spending the latter part of his life in Russia. Von Baer was the first to work out the development of the hen's egg layer by layer, so to say. He was also the first to see the original egg cell in a mammal, in 1827, twelve years before the formulation of the cell theory.

In comparing all the embryos that he could study, von Baer was impressed by the corresponding stages of development among different species. This uniformity has been called von Baer's "biogenetic law"—a general description of what we can observe in the development of many kinds of eggs into adult animals. Half a century later some biologists expanded this

idea into the theory that each individual *recapitulates* in his development the history of his race. The stages are supposed to represent all the types of his ancestors. In a general way this is true only as a restatement of von Baer's law. But, strictly speaking, it is not true, for example, that you once passed through a hydra stage or a fish stage. All we can say is that each of us has passed through stages which resemble corresponding stages in many classes of animals (see illustration, p. 459).

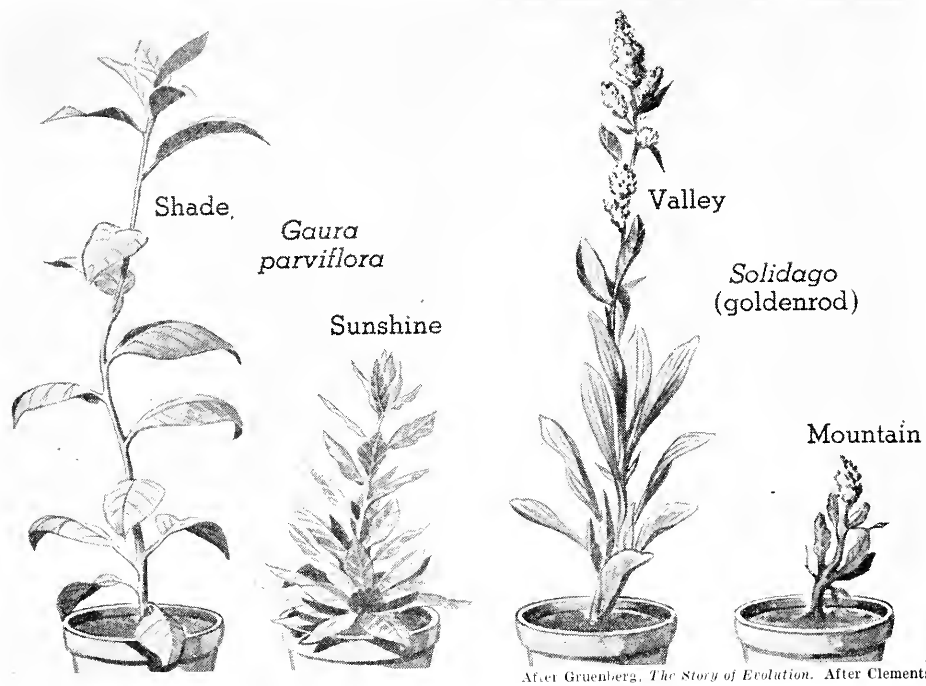
What Brings About Differentiations during Development?

Conditions for Development External conditions influence the development of organisms, just as they influence growth or metabolism in general. Thus plants growing in northern regions, with long days and short nights, during the summer, mature more rapidly than those grown from the same stock in regions having shorter days (see pp. 251-252). The submerged leaves of certain plants are quite unlike those growing above the surface of the water (see illustration, p. 203).

Temperature influences development in many ways, sometimes very strikingly. The eggs of frogs will develop into tadpoles very much more rapidly in warm water than in cold. Jacques Loeb showed that by changing the temperature it is possible to modify the rate of development and the life-duration of animals. Fruit flies, for example, live about eight weeks, from the egg to the end of adult life, at ordinary room temperature. At the temperature of a warm summer day (about 86° F), all their life processes are so speeded up that development is completed in three weeks. By lowering the temperature to 50° F we can retard all the life processes of the insect and stretch its life to nearly six months.

Temperature influences various aspects of metabolism and various tissues in different ways. Some species of butterflies and moths produce two broods a year, surviving the winter in the pupal stage. The spring form is often strikingly different from the late summer form in size and pigmentation. Experiments indicate that so-called *local races* or varieties of insects differ from one another chiefly, if not entirely, because of temperature.

Chemical Influences We can most easily observe the influence of chemical substances upon growth and development in the lower forms. But more complex forms also show modifications. Mollusks, crustaceans, and other animals have apparently become modified under natural conditions in which sea water is sometimes diluted by rains or concentrated by evaporation (see illustration, p. 359). Professor Charles R. Stockard (1879-1939), of the Cornell medical school, brought about amazing changes in development of the minnow *Fundulus* by changing the chemical composition of the sea water (see illustration, p. 360).



After Gruenberg, *The Story of Evolution*. After Clements

INFLUENCE OF ENVIRONMENT UPON PLANTS

Effects of excessive sunshine are shown in the first pair of plants. Effects of low temperature and excessive loss of water are shown in the second pair.

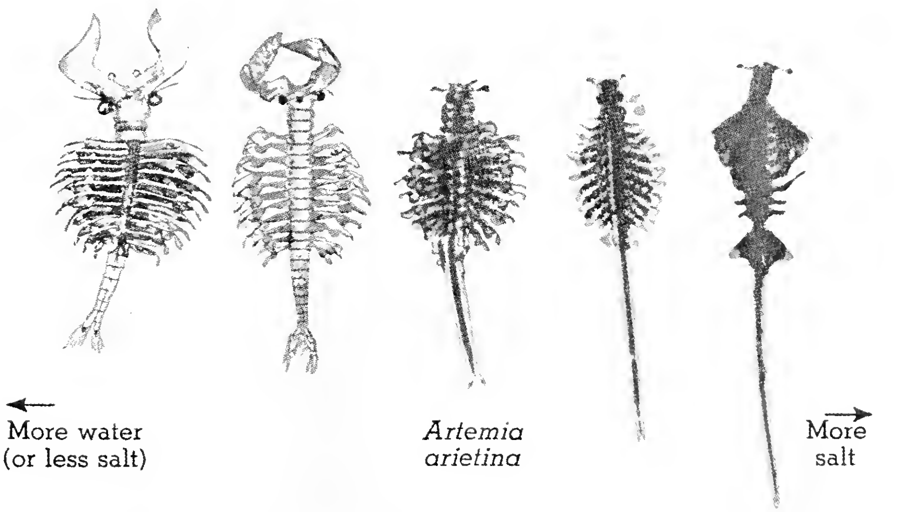
We have come to take chemical influences for granted in all protoplasmic activities, both as foods and as poisons. We have also come to think of the vitamins and hormones as chemical modifiers of protoplasm. But growth is not the same as development, and the two processes are not necessarily influenced in the same way by any particular chemical.

Inner Factors Temperature, light, moisture, chemicals, oxygen, and the like influence metabolism in many species. But what is it that brings about differentiation in the first place? One way of thinking about what happens during the progressive change from a single cell (or a few similar cells) to the many millions of differentiated cells is to follow cell-divisions step by step.

When two daughter cells are formed, they are apparently just alike. But if they remain clinging together, each has a surface flattened against the other. These cells are no longer round, the same in all directions. After a second division, the four cells press against one another at different relative parts. After a division takes place in a horizontal plane, the food supply is different for the upper cells from what it is for the lower ones. Each cell comes to be influenced in a different way by pressure, food supply,

exposure, and so on. We may, then, suppose that its metabolism is modified in a distinct way. It may produce distinct substances or different proportions of by-products. Respiration goes on more rapidly in some cells than in others. The by-products of each cell will in turn influence neighboring cells somewhat differently. Differentiation, having once started, continues in all directions.

Twins and Quintuplets In a sense, differentiation begins with the very first cell division. The single cell has in it all the "makings" of a complete and complex individual which it in time becomes and which contains perhaps trillions of cells. But so has each of the two daughter cells into which the egg divides. This we know from the fact of *twins*. Experimentally, the two cells in the two-celled stage of a frog or fish or sea urchin or some other species can be separated. Each cell then rounds up and starts to divide again. Under suitable conditions, each develops into a complete individual—the two as much alike as true twins are known to be. In other words, a single egg has the makings of a complete individual; and half the egg also has the makings of a complete individual. If the two halves remain together, however, each produces only half an individual! Something must make the *two-together* different from the *two-separated*.



From Gruenberg, *The Story of Evolution*. After Abonyi

RELATION OF SALT TO DEVELOPMENT OF THE BRINE SHRIMP

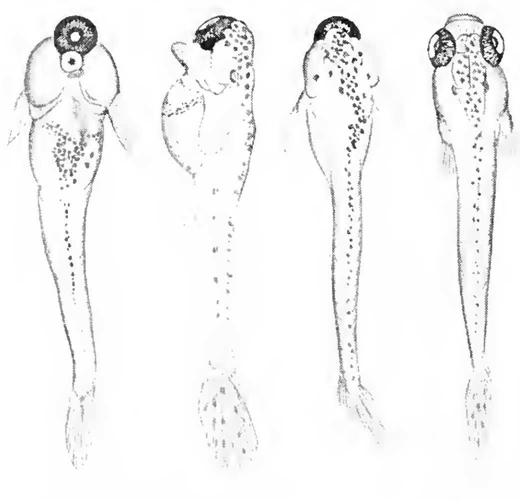
The brine shrimp, Artemia arietina, lives in brackish water. A Russian experimenter, Schmankewitsch, diluted the water slowly, and in other cases let the water evaporate so that the salts became more concentrated. The forms that appeared in the course of a few generations had been recognized previously as different "species". Other experimenters have repeated this process, which seems to be "reversible".

After the cells of the first pair have undergone the next division, so that there are now two groups of two cells each, we may again separate the daughter cells. Each of these four can produce a complete individual, so that perfect quadruplets result. In fact, the armadillo ordinarily gives birth to four babies that appear to have been derived from the same egg. With some species the cells of the third segmentation may be made to develop, yielding eight *identical* individuals. There is reason to believe that all the Dionne quintuplets came from the same egg (see illustration opposite).

From what we know, it is reasonable to assume (1) that at some stage in the growth of a mass of cells internal changes arise, and (2) that these, in turn, influence the development of other parts. It has been shown, in fact, that specific substances, or organizers, in various parts of the embryo influence the development of other parts in such a way that all the parts are kept related, or co-ordinated. There is evidence that *relative positions* in the embryo also influence the development of tissues and organs. However, this may mean the same thing, namely, that particular substances, produced in particular regions, influence the behavior of neighboring or remoter cells in the course of development.

How Can We Tell that There Are Specific Organizers or Growth Substances?

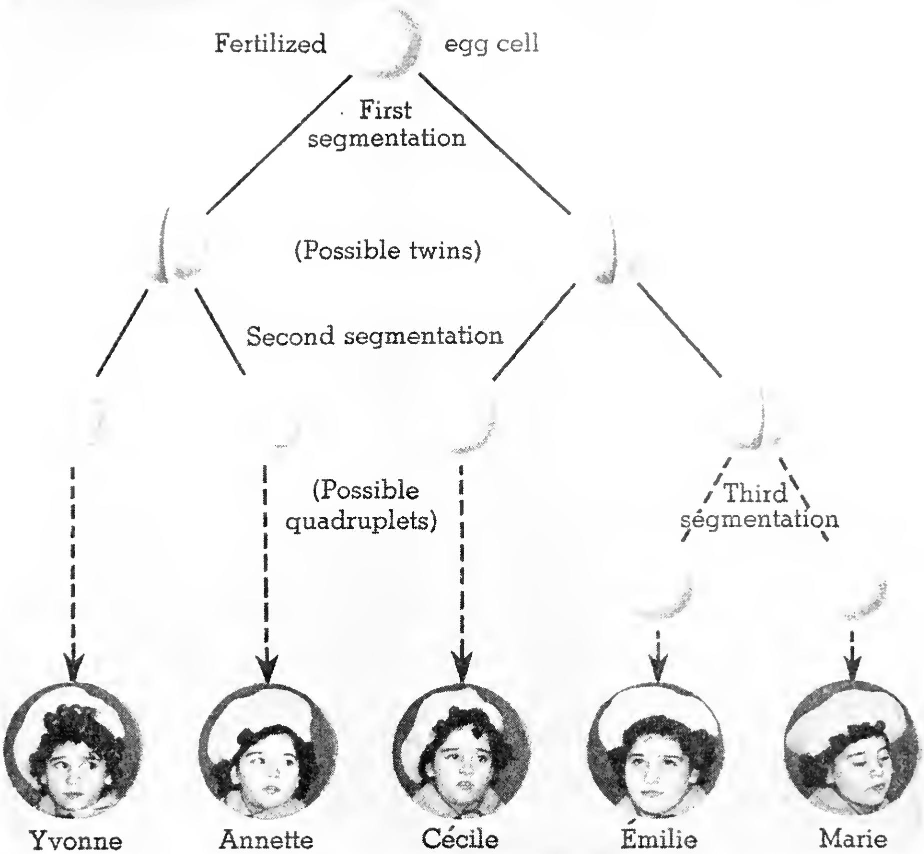
Position Is Everything—Almost In many games, in military operations, and in other human relations a great deal depends upon position. The position of cells in an embryo seems also to be important.



After Stockard

Ordinary minnow eggs develop into familiar minnows, with one eye on each side of the head. Practically all do so in ordinary sea water, which contains many different substances. By systematically changing the relative amounts of magnesium and calcium in the sea water, experimenters were able to make various types of freak minnows hatch out of the same batch of eggs. In one very striking form that hatched in water containing a high proportion of magnesium the two eyes started to develop on the right and left sides but steadily moved together and fused in the middle

CHEMICAL MODIFICATION OF DEVELOPMENT



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FIVE GIRLS FROM ONE FERTILIZED EGG

Each cell resulting from the first two or three cell divisions of a developing embryo would seem capable of becoming a complete individual. The most reasonable interpretation of the resemblances and differences among the "Quints" is that after the second cell division, three of the four cells developed into Yvonne and Annette and Cécile, while the fourth cell divided again, developing Émilie and Marie

Each of the cells resulting from the first three or four segmentations of the egg is capable of developing into a complete individual. In some species the capacity to form individuals is present in later cell-generations. By the time the embryo has reached the two-layer stage (see page 351), each part is fairly well set for its "destination". The end which is to become head is already determined. The parts that are to form skin and nerves are already distinct from the parts that are to form the food tube. Cells removed from the outer layer, or ectoderm, can keep on growing in a suitable fluid. But they will grow only ectoderm cells. Similarly, endoderm cells removed

from an embryo will grow only endoderm cells. Each part seems to carry on according to its position.

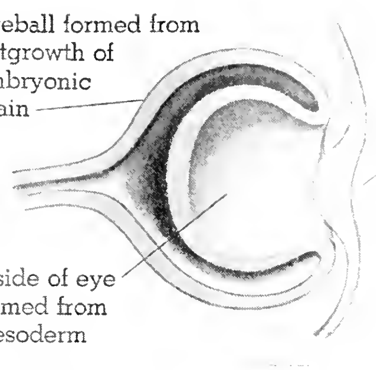
But position is not absolute. It is always in relation to something else. In the embryos of salamanders and frogs and other mammals we soon recognize parts that are to become brain, parts that are to become eyes or legs. Is the character of every tissue or organ already fixed at this stage? In one series of experiments a bit of tissue that would ordinarily have become eye was transplanted to the abdomen of an embryo, and a piece of leg tissue was transplanted to where wing should have developed (see illustration below). The eye-prospect became an eye, and the leg-prospect became a leg. Here the cells developed what we might suppose to have been their "natural" qualities, those belonging to the position from which they were taken.

A Master Organizer In the gastrula, or cup, stage, the ectoderm and the endoderm run together at the edge (see illustration, p. 351). The upper edge of the opening, called the "dorsal lip", seems to be a special center of protoplasmic activity. If a bit of this tissue is grafted on any part of an embryo, *it starts to develop a new embryo.* It apparently influences all the surrounding cells so that, as they grow and multiply, the mass shapes itself in relation to these dorsal-lip cells. Chemical study of these cells has located in them special "organizer" substances.

After Viktor Hamburger

GROWING ORGANS OUT OF PLACE

When the eye-bud in a chick embryo was grafted on the side of the abdomen, it developed into a complete eye, although the nerve connections were not established. The transplanted portion developed according to characteristics normal to its tissues



INTERACTION OF DEVELOPING STRUCTURES

The eyeball and retina develop as an outgrowth of the brain in the young embryo, whereas the lens develops as an ingrowth of the skin. If the eye-bud of an embryo is removed at an early stage and implanted under the skin on any other part of the body, the skin cells will develop a lens, where it cannot possibly be of use

Even young tissues act in specific ways. It is therefore possible that there are several or many organizer substances. In any case, the evidence shows that the parts of the embryo probably act on one another during development through chemical substances.

In some very clever grafting experiments Hans Spemann (1869–1941), a distinguished German biologist, used embryos of two different kinds of salamander. Spemann removed bits of *skin* from the abdomen of a salamander embryo and grafted it on the *brain* of one of the other type. In this position the skin cells developed brain, but they retained the character of their own species. Let us suppose that these developments were determined by the presence of organizer substances. We should then say that the organizer in the brain region changed skin cells into brain tissue, while the organizer in the skin cells determined the appearance or perhaps the pigmentation of the new (brain) cells formed.

More striking are experiments in which organs are made to develop in strange locations. In many vertebrates the eye is formed as an *outgrowth of the brain*, at a very early stage. The lens, however, is formed by an *ingrowth of the skin*, above the eyecup—but it takes something in the eyebud to make skin cells form a lens (see illustration above). Again, the external eardrum of the frog, which is easily examined, is formed by the regular skin cells above a ring of cartilage. If this cartilage is removed in the embryonic stage and grafted under the skin on the back or side of the frog, the local skin will become thin and form the peculiar eardrum tissue.

Thousands of experiments have been carried out on embryos of many species. The results agree with the notion that particular substances are

formed in the embryo, and that they influence the growth and differentiation of tissues and organs. At later stages, as we all know, further development is influenced by exercise, food, sleep, disease, and other factors. But in the early stages, when definite organs are already recognizable, some of these, by producing hormones, influence further development.

In Brief

There has never been a clear demonstration of "spontaneous" generation; all plant and animal individuals are assumed to have originated from previous life.

Every organism starts life as a single cell.

The single cell from which the complex individual develops has in it all the potentialities of the individual, but probably has not structures corresponding to all parts of the adult.

In each species the development proceeds through fairly consistent stages, which are sometimes very distinct.

Groups of species are remarkably similar in the early stages of development, although quite distinct later.

In some respects each individual recapitulates, in his own development, the history of the race.

The rate of growth and the longevity of a cell vary with the specific nature of the protoplasm of which it is composed.

The parts of a developing embryo influence one another, probably through the formation of specific chemical substances.

EXPLORATIONS AND PROJECTS

1 To find out how fast plants grow, and what parts grow most rapidly, mark growing plants at equal intervals and watch for alterations of levels. Plant seeds of sunflower, beans, corn or tomatoes and grow to maturity. Place India-ink marks on stems from time to time as stems elongate. When seedlings are only two or three inches tall, make marks $\frac{1}{4}$ inch apart; later use 1-inch intervals. Summarize results to answer the questions raised. Record growth-differences as indicated by changes in the relative positions of ink spots. Measure the height of the plant periodically and plot its growth.

2 To investigate the development of the chick embryo, incubate fertile eggs, and open one or more day by day to observe the changing embryos.[1] Since the

[1]Place eggs under a sitting hen, or else in an incubator at 103°F. Eggs should be turned each day. The incubation period is 21 days. A convenient way to plan for the study of chick embryos is to place one or more fresh fertilized eggs in the incubator each day for 21 successive days, dating each egg, and then to open all eggs at once for study. To open eggs, insert fine-pointed scissors through the shell and membrane and cut out a circular portion.

embryo always floats on top of the yolk, it may be readily observed with a hand lens (or in later stages without such lens) by lifting off a piece of the shell.

Watch for the first appearance of circulatory and nervous systems, and for limbs. Note the distinguishable parts that become structures of the embryo or of later stages; note what functions other parts of the egg serve. Make a summary record of the development, with the help of drawings or photographs.

3 To study the growth and development of houseflies, grow cultures under observation in the laboratory.[1] Note (*a*) what conditions favor the growth and development of the species studied; (*b*) the number of offspring; (*c*) the character and amount of parental care; (*d*) the habits of the species that make them particularly dangerous as carriers of disease or otherwise; (*e*) what methods suggest themselves for their eradication.

4 To make a study of the early development and metamorphosis of frogs, toads or salamanders,[2] watch the animals through the stages, in an aquarium. Make careful notes and appropriate drawings showing the different stages in the development.

5 To find out how the snail develops, keep an egg-mass from an aquarium in a small jar, where development can be traced in detail. (Snails require no attention whatever if they are supplied with aquarium water containing a little vegetation.) Examine the egg-mass regularly with a good hand lens or with a microscope. Follow the development of the embryos. Describe the embryonic development.

6 To study the life history of a fish, observe the early and mature stages in a fish hatchery. Find out how the eggs and sperms are obtained and used in the artificial fertilization of fish; how the young are reared, and how they are transferred to streams and lakes. Describe the early development.

7 To find out whether human proportions change between infancy and adulthood, obtain several measurements of distance from foot to hip, hip to shoulder, and shoulder to top of head, and plot the average measurements for each dimension and for each age. Compare the separate curves as to slopes, which indicate the relative rates of growth. Note which measurement changes the least from infancy to maturity, and which the most. Find out whether there is any period in development when growth takes place at an increased rate in all the measurements. Summarize conclusions and interpretations.

[1]To raise a generation of houseflies, place a pair of adult flies in a screened jar or cage half filled with manure, or expose the jar for a day or two where there are flies. Use sufficient manure to keep the mass moist, though not wet.

[2]Collect eggs early in the spring from shallow pools along the borders of a pond or stream. Supply green algae as food, and change the water frequently.

1 How does growth in many-celled organisms resemble that in one-celled organisms? How do the two kinds of growth differ?

2 How do the results of cell-division in a one-celled organism differ from the results of cell-division in a many-celled organism?

3 How does the one-celled stage of a bean plant become a many-celled bean plant?

4 What changes besides increase in size take place in an organism passing from the one-celled stage to maturity?

5 In what parts of the human body does growth take place? In what parts of a tree's body?

6 In the one-celled stage various species are not unlike. What brings about the vast differences among different kinds of adult organisms?

7 What theories account for the successive steps in the development and differentiation of an embryo?

1 Does every animal start life as a single cell?
2 How does the beginning of a new animal resemble the beginning of a new plant?
3 Is there sex in plants, as well as in animals?
4 How do different kinds of animals reproduce themselves?
5 Does any animal species reproduce in more than one way?
6 Do all species of plants produce seeds?
7 How do seedless plants multiply themselves?
8 In what ways are eggs and seeds alike?
9 In what ways are eggs and seeds different?

The life of every individual, plant as well as animal, comes to an end—after only a few minutes or after many centuries. The rolling seasons bring increase and abundance, followed by drought and killing frost. Whether through privation or illness, through violence or mischance, or through the natural internal changes, everyone must die. Dying is part of being alive.

The life of the individual continues, for longer or for shorter, as the dying protoplasm is constantly replaced within each cell. But while each individual life comes to an end, life goes on. The species or race may continue to live for thousands and thousands of years. How are dying individuals replaced? How does life go on from season to season, from generation to generation? How does a species reproduce itself?

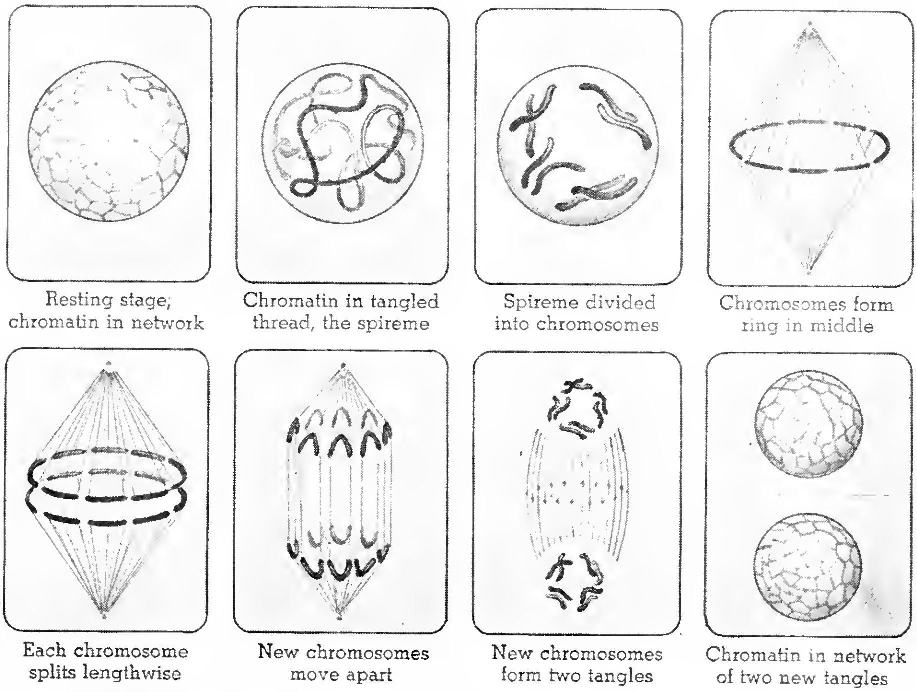
How Is Reproduction Related to Growth?

From the End to the Beginning[1] Living plant and animal cells often end their existence by dividing into two. When we break a rod of wood or glass into two pieces, we double the number of rods, but we do not increase the amount of wood or glass. Nor do we destroy any glass or wood. We destroy merely the integrity or identity of the original rod.

In much the same way, a one-celled plant or animal ends its existence by dividing into two. It neither increases nor decreases the amount of protoplasm. It distributes its living matter between two new cells, which come into being through this process. The mother-cell at the same time destroys its identity; it ceases to exist. We might say that a pleurococcus cell or an ameba is born an orphan.

Individual cells are constantly being devoured by other organisms, or killed in other ways. When a cell divides, there is a multiplication of cells. We may think of this as a kind of reproduction in one-celled species or as a

[1]See Nos. 1 and 2, pp. 394–395.



NUCLEAR CHANGES DURING CELL DIVISION

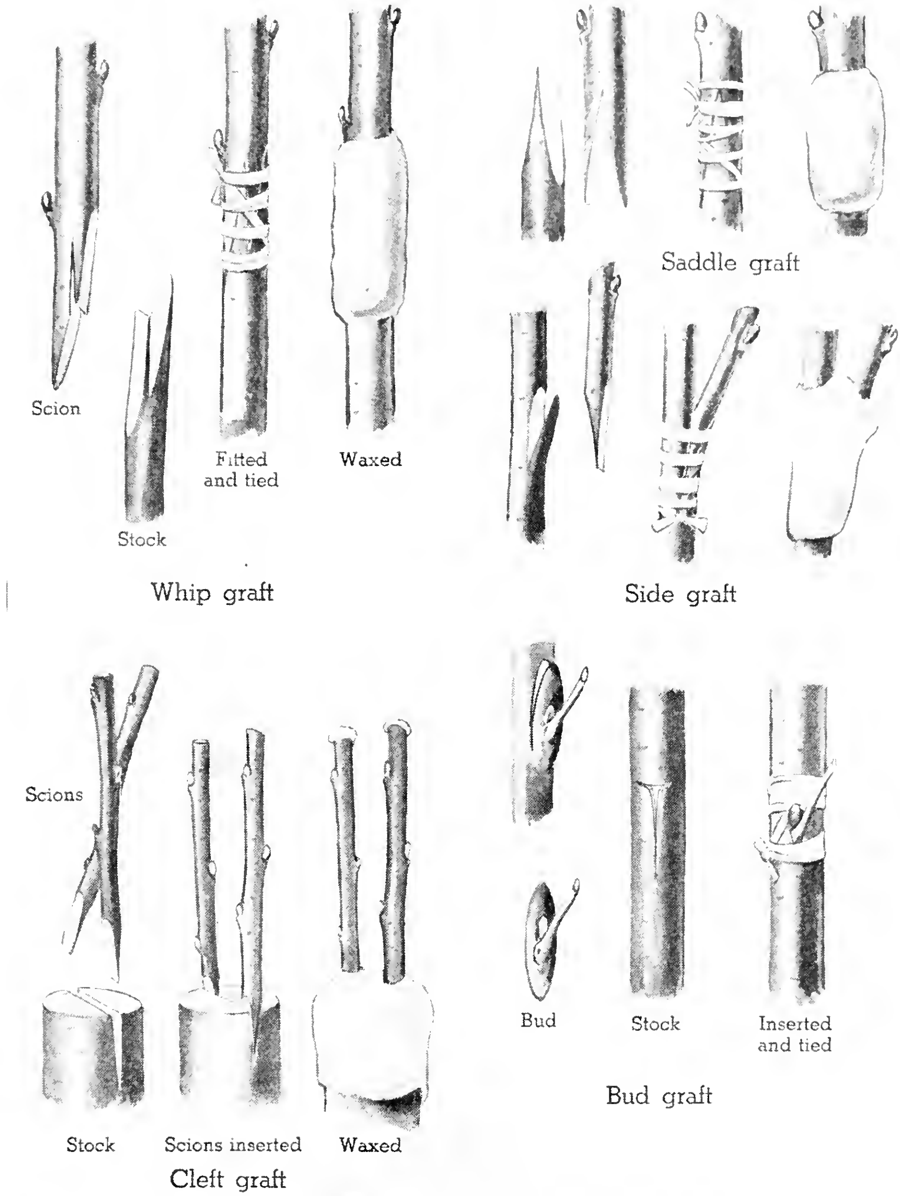
The spireme separates into a definite number of chromosomes. Each chromosome splits lengthwise; each half becomes part of the nucleus of one daughter cell. The chromatin becomes exactly divided. The daughter cells have exactly the same number of chromosomes as the parent cell

stage in the growth of many-celled species. But the protoplasm of a one-celled plant or animal seems to be able to grow and then divide, without end. Of course no single cell continues to live forever, but the protoplasm —as distinct from the individual—appears to be immortal!

Nuclear Division[1] The sameness of the protoplasm, through all the successive cell-divisions, appears to be related to the behavior of the cell nucleus (see illustration above). We are impressed by the precise division of the chromatin material. It is possible that other parts of the nucleus, and the cytoplasm, also divide in the same precise manner. But of that we cannot be sure, since the substances are for the most part indistinguishable with our present methods of study.

In multicellular plants and animals cell-division is an essential feature of development, as well as of growth, for at certain stages it results in new kinds

[1]See No. 3, p. 395.



TYPES OF PLANT GRAFTS

For successful grafting, the cambium tissues of the bud or scion must be placed in contact with the cambium of the stock, to allow nourishment to pass from one to the other. Speed is essential to avoid drying of the delicate cut tissues. Grafting is carried out in the winter or early spring, while all buds are dormant. Budding is done in the late summer or early autumn—the bud not opening until the following spring

of cells and tissues. Under special conditions, cell-division brings about the healing of wounds, breaks or injuries (see page 228). And through regeneration cell-division may give rise to new individuals; a fraction of a worm or a starfish, for example, may become a new individual.

Regeneration and Reproduction[1] Fruit growers propagate new lots of individuals by setting out slips, or cuttings, from especially desirable plants, and having them take root. Even where cultivated plants bear seeds, it is sometimes more practicable to use this vegetative propagation than to depend upon seeds. The strawberry and other common plants normally split themselves into multitudes of individuals through vegetative propagation (see illustration, p. 372). A long shoot of forsythia or of wisteria may droop to the ground and take root; later the connection with the parent plant dies away. The horticulturist regularly makes use of this process, as in "layering" raspberries: he brings a stem over and fastens it in contact with the ground until it establishes itself by means of roots (see illustration, p. 373).

For all practical purposes, new individuals *do* arise from cell-division in budding, regeneration, and other growth processes. But we commonly distinguish between *growth*, which means an increase in the quantity of living matter, and *reproduction*, which means the bringing of new individuals into being. Moreover, we usually think of reproduction as an event or process that separates one generation from the next.

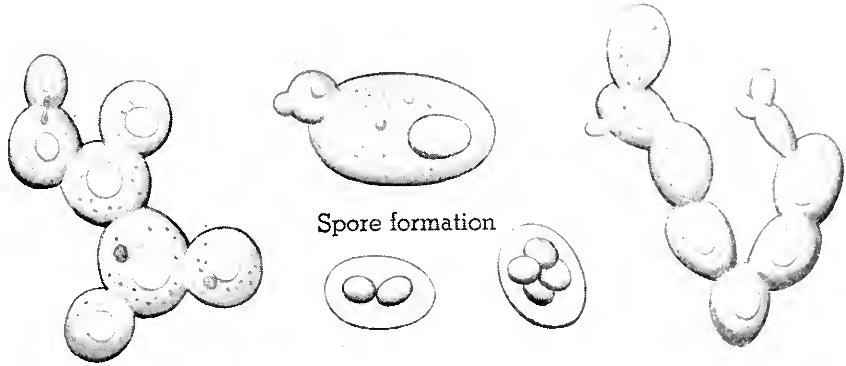
How Is Reproduction Different from Growth?

Spores and Cysts[2] If the conditions for growth become unfavorable, some species of protozoa form a thick cell-wall inside of which the protoplasm may remain indefinitely inactive. In this incased state, or *cyst*, the animal may resist drought or frost, or even the digestive juices of some stomach into which it may get. The cyst is thus a resting stage in which animals can survive adverse conditions.

Among the simplest plants unfavorable conditions lead to the formation of a somewhat similar resting stage. Yeast cells, for example, divide the protoplasm into four parts, each of which puts out a thickened wall (see illustration opposite). Such a special cell is called a *spore*, and is able to resume growth when conditions are again favorable. Spores are produced in nearly all species of plants and in some animals. They are also usually formed in large numbers and are very resistant to unfavorable conditions. In the spore stage some kinds of bacteria cannot be killed by boiling water.

One class of protozoa, the Sporozoa (see Appendix A), consists of parasitic forms which reproduce by means of spores. These special cells result from

[1]See No. 4, p. 395. [2]See No. 5, p. 395.



THE YEAST PLANT

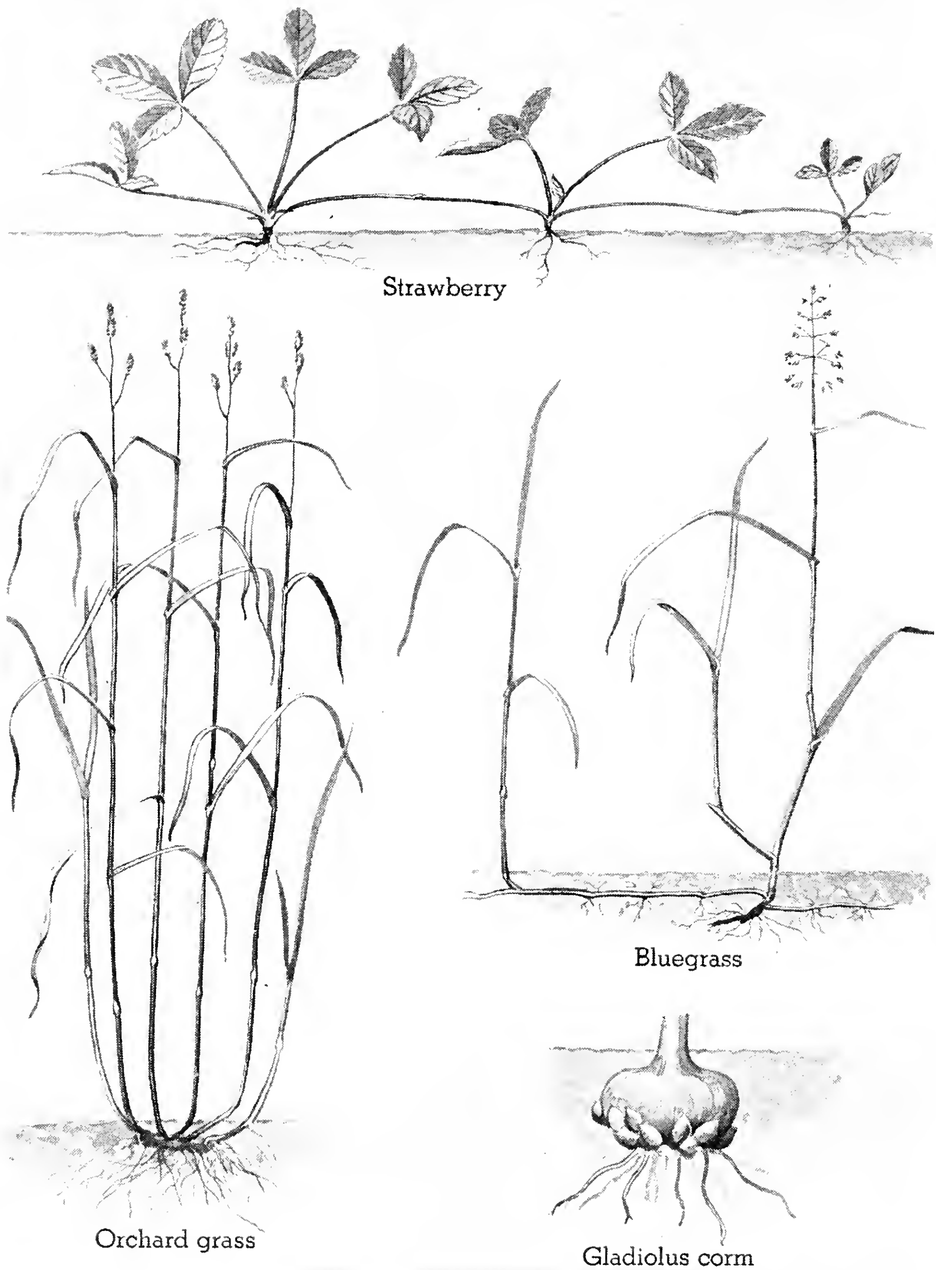
The cells of this plant push out buds, which drop off at various stages, and continue to grow and bud so long as food and other conditions are favorable. Under certain conditions the protoplasm of a cell divides into two and then four parts, each of which may remain inactive for an indefinite time. Such resting cells are called spores

successive cell-divisions of the growing protoplasm, and they can dry up and withstand conditions unsuited to growth for a long time. The malaria parasite belongs to this class. The plasmodium, or ameba-like stage, of this species is parasitic in red blood corpuscles. When it has grown as far as possible in a corpuscle, the protoplasm divides into a large number of spores, which are discharged into the blood plasma (see illustration, p. 622).

Spores are so small, and they are produced in such tremendous quantities, that they become widely scattered in the air. We can hardly find a sample of dust that does not contain spores of several different species, including, of course, bacteria. This accounts for the difficulty of keeping organic matter from spoiling at ordinary temperatures in the presence of moisture. The molds and mildews and yeasts and bacteria that spoil bread and other food, cloth, leather, paper, damp hay, wood, and so on get started from such spores.

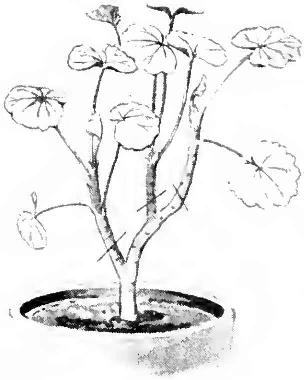
In mosses we can see tiny puffs of spores come out of the graceful little capsules at the tips of stiff bristles (see illustration, p. 412). On the backs of fern fronds we can see the dark "fruiting bodies", which are masses of spore capsules (see illustration, p. 387). The yellowish pollen which ardent flower-smellers get on their noses consists of tiny spores. And it is such flower spores, scattered by the wind, that have brought certain species of plants into disrepute with many people because they are responsible for hay fever and asthma.

We may think of these most widely scattered dust particles, produced in inconceivably great numbers, as the resting stages in which species keep their hold on life during the lean seasons. We may think of them as special means for spreading out in space and so improving the chance of finding a favorable



VEGETATIVE PROPAGATION

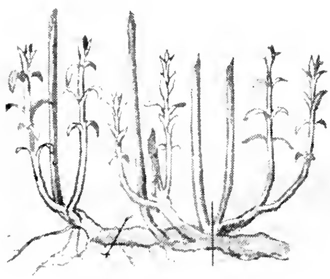
Plants naturally increase in numbers through vegetative propagation. New individuals develop from a portion of the parent plant, before or after that becomes detached



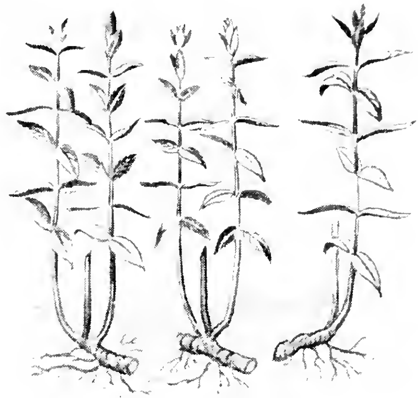
Geranium plant

Cuttings in water

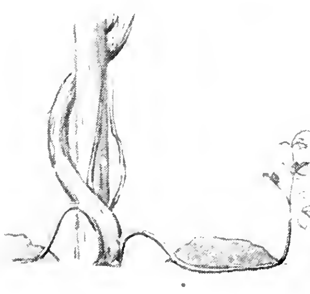
Rooted cuttings



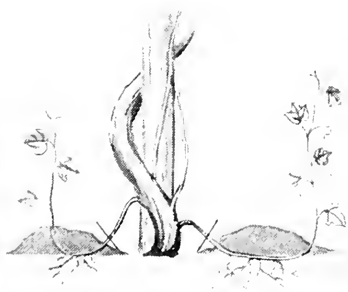
Phlox plant



Phlox plant divided



Vine layering

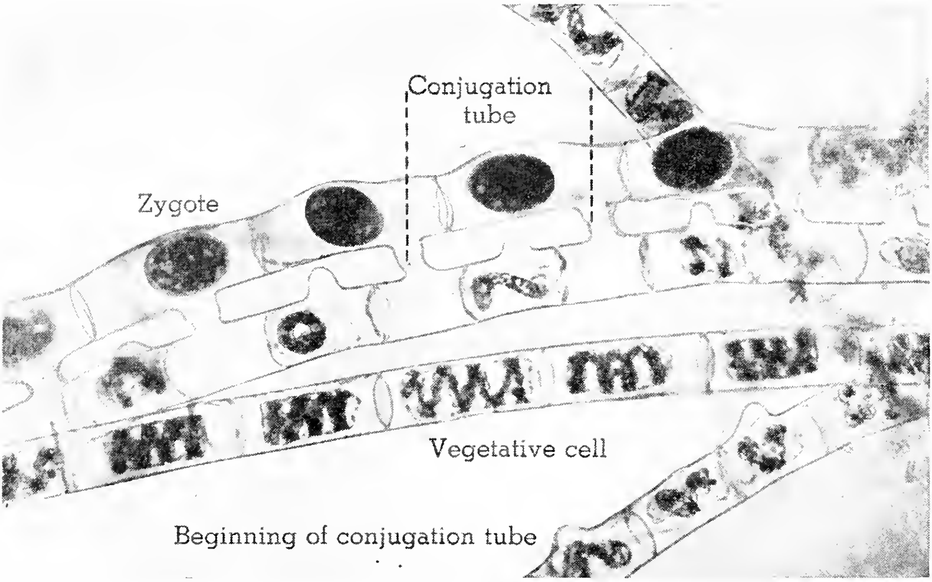


Rooted stem

New plants

ARTIFICIAL PROPAGATION OF PLANTS

By propagating vegetatively we can get innumerable plants from a single choice specimen. We can thus reproduce in quantity a variety of flower or fruit that suits our fancy or our needs, which we could not get so surely or so quickly in any other way



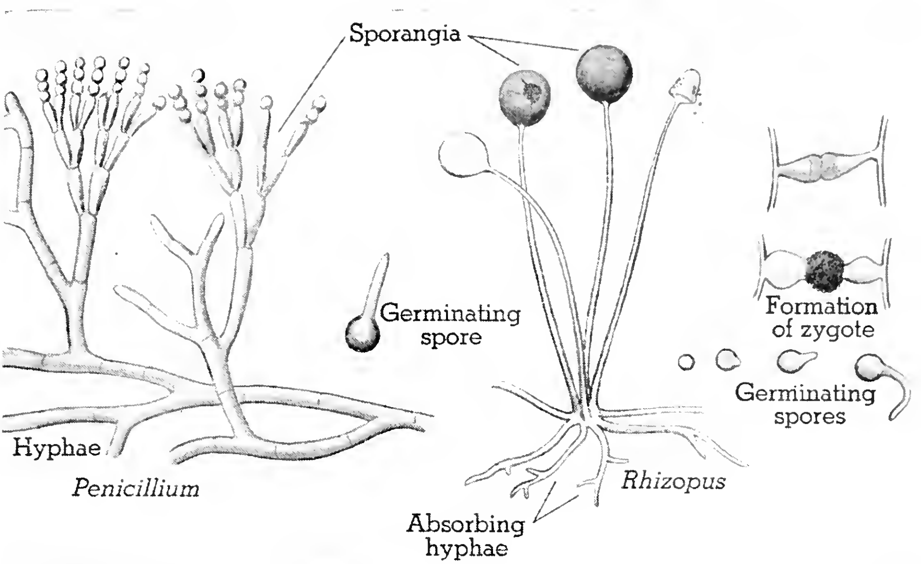
CONJUGATION IN SPIROGYRA

In threads of Spirogyra lying close together, the cells put forth projections, which grow toward their opposites. The projections dissolve at the point of contact, and the protoplasm of one cell moves entirely into the opposite cell. The fused protoplasm becomes a single spore with a thick wall

location for resuming life's activities. Or we may think of them as the "germs" which initiate new plants and animals to replace the life that has come to an end.

Cell Fusion Like the cells of growing tissues, spores result from a dividing up of existing protoplasm. We think of spores as highly specialized *reproductive* cells, for they "do" nothing unless there is a chance to start growing a fresh line of protoplasm; and when a spore does start a new individual, it at once goes out of existence itself. Now, in addition to extending life by growth or by spores, most plant and animal species reproduce by a method that is in a sense the reverse of cell-division. Under certain conditions two distinct cells unite, or fuse, into one cell. This new cell that results from such a joining is then the first cell of a new growth.

In the common pond scum spirogyra, the individual cells all look alike; and they are almost independent of one another, although they cling together in long threads. Each cell has chlorophyl and manufactures its own organic food. In the course of a few sunny days in the spring, a pond may become covered over with millions of the green threads. In darkness and at low temperature, as the threads become entangled in the water, two cells lying opposite each other may put forth budlike outgrowths which meet end to end. The cell-walls at the point of contact dissolve, and the protoplasm from one



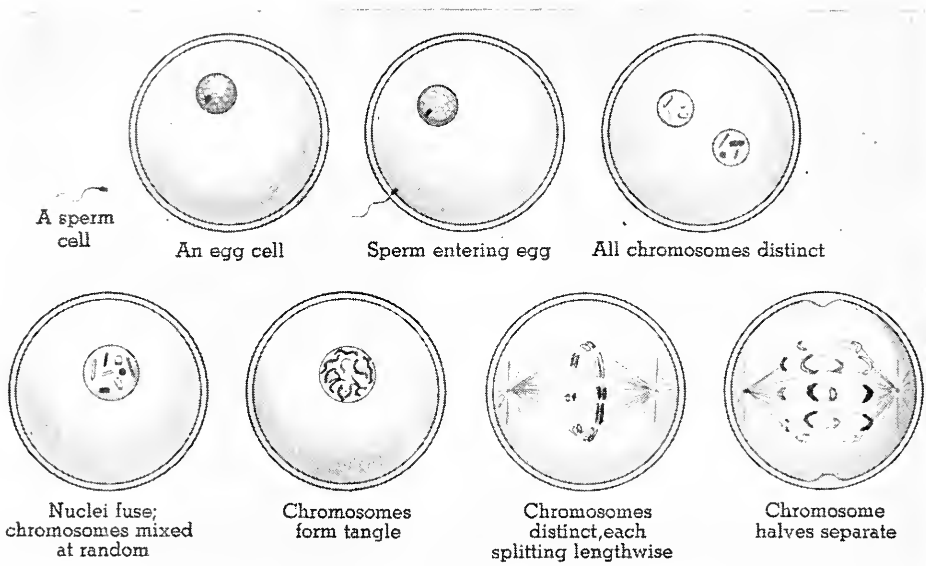
SPORES IN COMMON MOLDS

Spores are generally formed by the repeated division of protoplasm. In the black mold, spores are formed in an enlarging cell at the tip of a vertical thread; this results in a capsule, which breaks and lets the spores scatter. In the blue mold, spores are separated off from the terminal branches of threads. In the black mold two threads sometimes meet, so that the protoplasm combines into a sporelike cell called a zygospore

of the cells passes over into the opposite cell; the two masses of protoplasm unite and form a new kind of cell (see illustration opposite).

Like a spore, this new cell (which forms a thick, dark cell-wall) is able to start a new growth after waiting indefinitely through unfavorable conditions. But it is unlike a spore in its origin, for it arises from the *conjugation*, or uniting, of two pre-existing cells. The cells that take part in the conjugation are called *gametes*, from a Greek word meaning "to marry"—that is, to join, or unite. The cell that results from the conjugation is called a *zygo*-spore—that is, a spore formed by a yoking, or joining together. It is sometimes called a *zygote* for short.

The common molds are widely distributed by the millions of spores which they produce by the successive division of the protoplasm. In addition, zygotes are produced in black mold by the fusion of protoplasm from two different hyphae (see illustration above). There are distinct strains in the species, and conjugation can take place only if threads of two different strains come together. There are no doubt chemical differences between the two strains of mold, but what the differences are has not yet been found out.



THE CHROMOSOMES IN FERTILIZATION

The essential fact about fertilization, in both plants and animals, is the uniting of chromosomes from two cells into one nucleus. Although the male and female gametes are quite different in most common species, the chromosomes supplied to the zygote by the two parents are almost identical

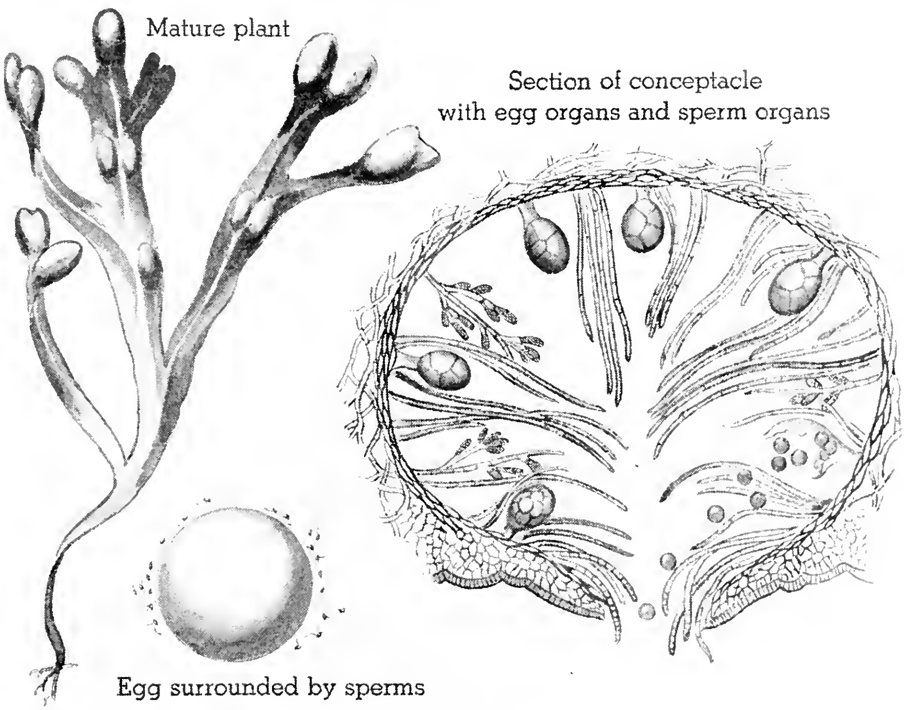
In most ancient civilizations people believed that "fruitfulness", or the producing of offspring, in many plants, as well as in most animals, depends upon two parents, male and female. They recognized and accepted the fact that the members of most species exist in two forms, male and female. "Male and female created he them." The oldest myths and legends make a point of sex differences. But the exact connection between sex and reproduction could not be known until the microscope had been invented and improved.

It was as recently as 1875 that a German physician and embryologist, Oskar Hertwig (1849–1922), was able to show that the essential fact in fertilizing, or "making fruitful", is a *uniting of two different cell nuclei into one* (see illustration above).

While the two gametes are indistinguishable in some species, the combining cells in most plant and animal forms differ from one another in many ways. And in most species of animals the two kinds of germ cells, or gametes, are borne by the two different kinds of individuals, male and female. The female gamete is the *egg*, and the male gamete the *sperm* (see illustration, p. 388). The union of a sperm with an egg, or fertilization, takes place in all sexual reproduction.

Vertebrate Reproduction[1] In backboned animals the reproductive or *germ* cells are borne in special organs called *gonads*, and they are usually produced in two different individuals. The gonads are generally paired organs located in the hind part of the abdomen. The eggs, or ova, are formed in the *ovary* and are discharged into the general body cavity. They then pass through a long twisted egg-tube, or *ovi*-duct, eventually reaching the exterior.

The sperms are produced in *spermaries*, or *testes*, and are discharged to the exterior by way of special ducts (see illustration, p. 379). In fishes that we commonly use as food we can often find the ovaries with their masses of eggs, or "roe", in the female specimens, and the corresponding spermaries, or "milt", in male specimens. In the other classes of backboned animals (reptiles, amphibians, birds, mammals), the essential organs are the same. The distinctive variations are related to the manner in which the eggs and sperms



REPRODUCTION IN ROCKWEED, OR BLADDER WRACK

The eggs and sperms of the bladder wrack are discharged into the water. Numerous sperms swarm around a single egg until one sperm unites with it. The result of the union is a fertilized egg, or zygote

[1]See No. 6, p. 395.

are brought together and to the protection and nourishment of the new individual.

Aquatic Vertebrates[1] Among the fishes the female usually deposits the eggs in quiet places at the bottom of the sea, near shore, or in quiet pools of rivers. Then the male swims over the eggs, dropping a quantity of the *seminal* fluid which contains sperms (see illustration, p. 380). The countless sperm cells swarm about the heavier egg cells. One of the many sperm cells swimming around a particular egg forces itself through the covering membrane, and the fusion of the two cells takes place. As soon as the nucleus of the male gamete and the nucleus of the female gamete have united, the combined nucleus begins to divide, and so the development of a new fish is started.

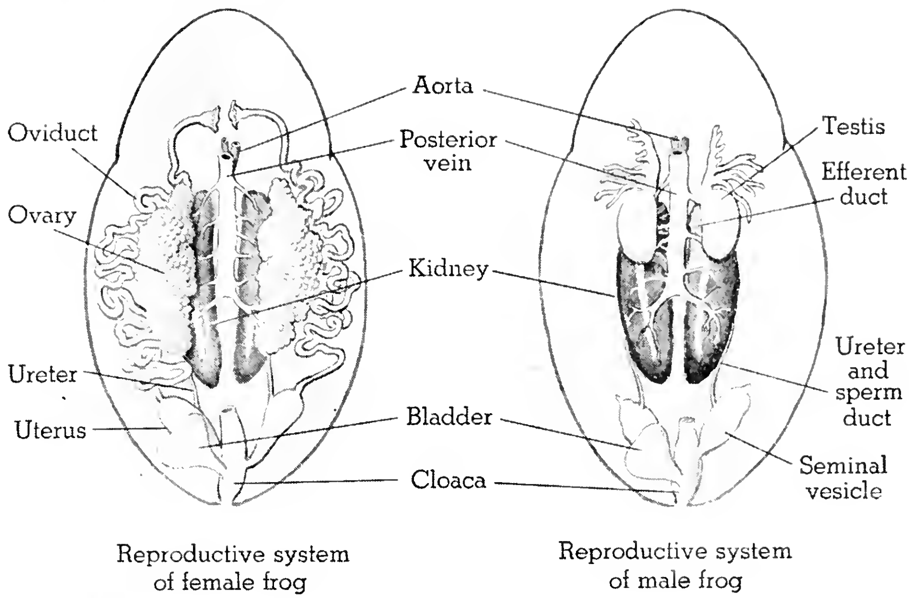
Whether or not the sperm cells are attracted to the eggs by specific chemical tropisms, two conditions favor fertilization: (1) both gametes are discharged into the water in the same region and at about the same time; (2) the proportion of sperm cells to egg cells is enormous.

The egg cell of the fish contains a quantity of food material in addition to the living protoplasm. The young fish developing out of the fertilized egg lives on this accumulated food. In some species of fish one or both parents swim about in the neighborhood of the developing fry and protect them against destruction by their natural enemies.

Reproduction among Amphibians[2] In the common frog the male and the female are not ordinarily distinguishable. During the breeding season, however, the ovary becomes very much enlarged as the eggs are being formed, so that the female is rather swollen. In the spring the adult frogs come out of their winter sleep and move to the ponds. Near the edge of the pond a male gets on the back of a female and clasps her firmly with the front legs. During this copulation, or joining, the eggs emerge from the female, enclosed in a mass of gelatinous slime; at the same time the male discharges the seminal fluid over the emerging eggs. Fertilization thus takes place in the water. The parent frogs swim off and pay no further attention to the fertilized eggs or to one another. In some species of amphibians, however, there is a great deal of parental care (see page 421).

Among all the vertebrate animals above the amphibians the eggs are fertilized while they are still inside the mother's body. But internal fertilization takes place also among several groups of amphibians and even among fish. The little guppy, a tropical fish often cultivated in home aquariums, is an example of a *viviparous* species; that is, one in which the female brings forth "living" young, in distinction from *oviparous* species, which are "egg-bearing". Now most water animals discharge their eggs into the water, where they are fertilized by the swimming sperms. The oviparous reptiles and birds, as well

[1]See No. 7, p. 395.
[2]See No. 8, p. 396.



REPRODUCTIVE ORGANS OF THE FROG

Eggs discharged by the ovaries into the body cavity get into the funnel-like opening of coiled egg tube. Eggs become covered with gelatinous substance secreted by lining cells of the oviduct. Past the thin-walled enlargement of the oviduct, called the uterus, eggs leave body by way of the cloaca

The sperms are formed by cells lining the fine tubules that make up the spermary, or testis. The sperm cells float in the spermatic fluid, or semen. The semen is gathered into a duct that joins the urine-conducting tube from the kidney (the ureter), and is then discharged from the body by way of the cloaca

as insects, deposit eggs that hatch outside the mother's body, after they are fertilized inside the body.

Reproduction in Mammals[1] In mammals, including man and the other primates, the paired ovaries and testes develop from early budding of the endoderm into what later becomes the body cavity. As in all vertebrates, the gonads originate early in the embryo's development in close association with the kidneys. But the ovaries and the testes are complex organs: in addition to their gamete-producing functions, they produce special hormones, or endocrines (see page 314). In the males of nearly all mammals the testes change their positions in the abdominal cavity, gradually descending into a pouch, or bag, which extends outside the body wall. This is called the *scrotum*.

The ovaries consist of masses of cells that produce eggs only near the surface. The core of the ovary contains cells that produce the specific "female

[1]See No. 9, p. 396.

United States Fish and Wildlife Service

ARTIFICIAL INSEMINATION OF FISH AT A RAINBOW–TROUT HATCHERY

By stroking a mature female fish, the fish-breeder forces ripe eggs into a pan of water. Then he "strips" the seminal fluid into the water from a male fish

hormone", which is absorbed into the blood and carried to all parts of the body. As each egg ripens, it detaches itself from the ovary and floats in the fluid of the body cavity.

During *copulation*, the seminal fluid is discharged into the *vagina*, which connects with the lower end of the womb, or uterus (see illustration, p. 383). The sperm cells swim in the mucus secretion lining the womb, and into the oviducts. An egg cell descending the Fallopian tube may be fertilized at any point where the egg and sperm meet. The fertilized egg starts segmentation immediately after the fusion of the two nuclei.

The developing embryo attaches itself to the lining of the uterus by means of outgrowths, or "villi", through which food material is absorbed from the lymph of the mother (see page 423). At a certain stage in its de-

velopment, the new individual is pushed out of the mother's body by contractions of the uterus. The cord breaks off close to the abdomen; the scar formed is called the *navel.* Later the placenta and the cord are also forced out; this is the so-called "afterbirth".

How Do Invertebrates Reproduce?

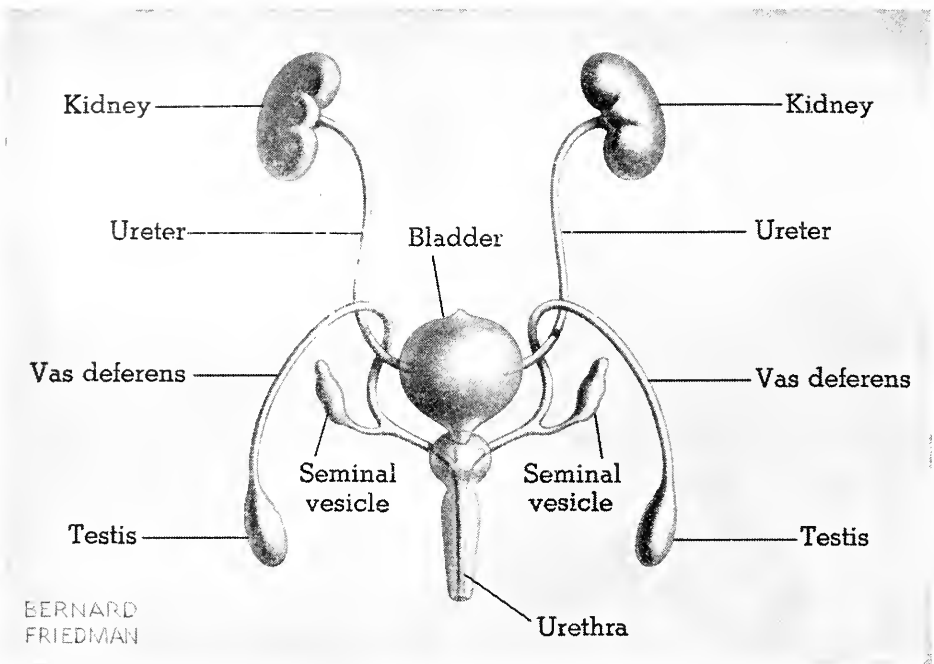
Reproduction among Insects There seems to be a direct relation between the modes of reproduction in different classes of plants and animals and the conditions under which the various species live. In the life of each individual organism the earliest stages of the egg's development are passed in water. Only in the more complex forms are the latest stages passed on land or in the air. But whereas spores appear, in general, to be adapted to endure and survive drought, sperm and egg cells are quickly killed when away from moisture. Some of the distinctive characteristics of land and air species may be regarded as adaptations to the fertilization of egg cells while they are still in the body of the mother.

Among insects, which of all classes of animals are most definitely adapted to life in the air, the sperm cells of the male, suspended in a fluid, are passed directly into a receptacle in the body of the female through a special duct, or tube. From this receptacle the sperm cells pass, a few at a time, into another space, in which the eggs are fertilized. A queen bee can retain a quantity of living sperms for two or three years, or even much longer. She forces sperms out of the receptacle from time to time as she produces new eggs.

Even in insects that normally lay their eggs in the water, such as mosquitoes, fertilization takes place within the body of the mother. There is a wide range, however, between species that leave the eggs as soon as they are laid and those others (like the wasps, bees, and ants) that build elaborate nests for the eggs and young, store away food, and actually nurse or protect the young.

Aquatic Invertebrates Among invertebrate animals living in the water, such as sponges, corals, starfish, clams, and some crustaceans, eggs and sperms are discharged into the water. The eggs contain relatively large amounts of food material and sink to the bottom. The swimming sperm cells swarm about the eggs. Fertilization takes place when one sperm penetrates the protoplasm of an egg.

When the nuclei of the germ cells have united, the fertilized egg cell forms a denser membrane. Other sperms cannot then enter. In some species of water animals, segmentation, or cell-division, starts immediately; in others there are varying intervals. In most species the fertilized eggs, like the gametes, are abandoned by the parents. In some invertebrates, however, the eggs receive a degree of mechanical protection. In lobsters and crayfish, for example, the eggs are fastened to the abdominal legs of the mother by a sticky substance,



MALE REPRODUCTIVE ORGANS IN MAMMALS

The sperm cells originate in the linings of fine twisted tubules that make up the mass of each spermary (testis). The seminal fluid accumulates in small reservoirs, the seminal vesicles. The tubes run together into common ducts leading into the urethra, which also carries urine from the bladder

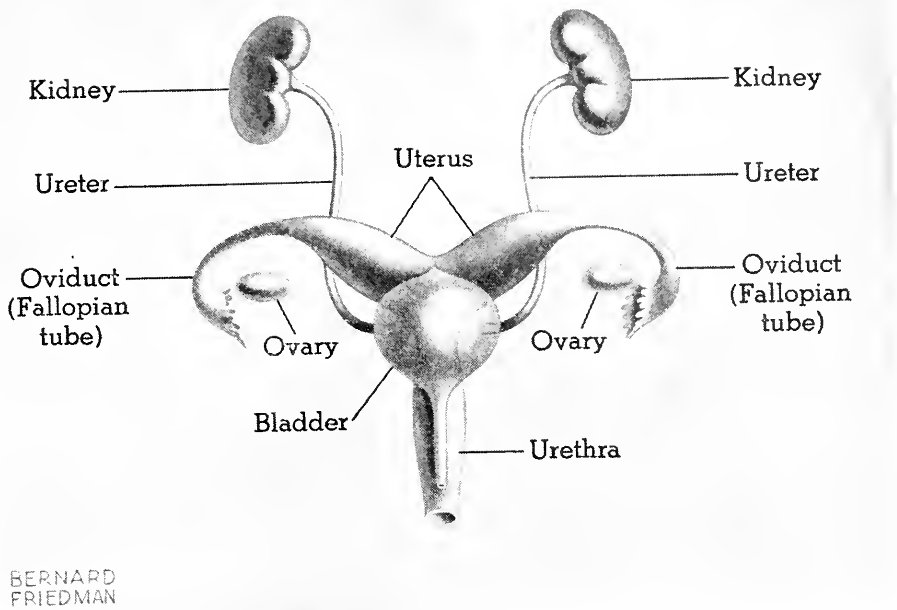
until the young are able to swim. Among the clams the eggs are discharged into the mantle cavity, where they are fertilized by sperms swimming in the water that circulates there (see illustration, p. 209).

Reproduction in Coelenterates[1] In the hydra and its relatives the individual polyps attach themselves at the base of the stalk. In some forms they remain permanently attached, in others only temporarily. In most species the stalk puts out buds, which become new polyps. In this way a colony of countless branches is formed, each one ending in a polyp—as in coral colonies.

Among some of the species related to the hydra and the sea anemones there is a regular alternation between a generation that reproduces sexually—that is, by means of conjugating gametes—and a generation that reproduces by budding, or without sex (see illustration, p. 384).

Two Kinds of Generations[2] Since many species of plants and animals reproduce vegetatively, or by means of spores, as well as sexually, we may wonder whether the individuals that reproduce in these two different ways

[1]See No. 10, p. 396. [2]See Nos. 11 and 12, p. 396.



FEMALE REPRODUCTIVE ORGANS IN MAMMALS

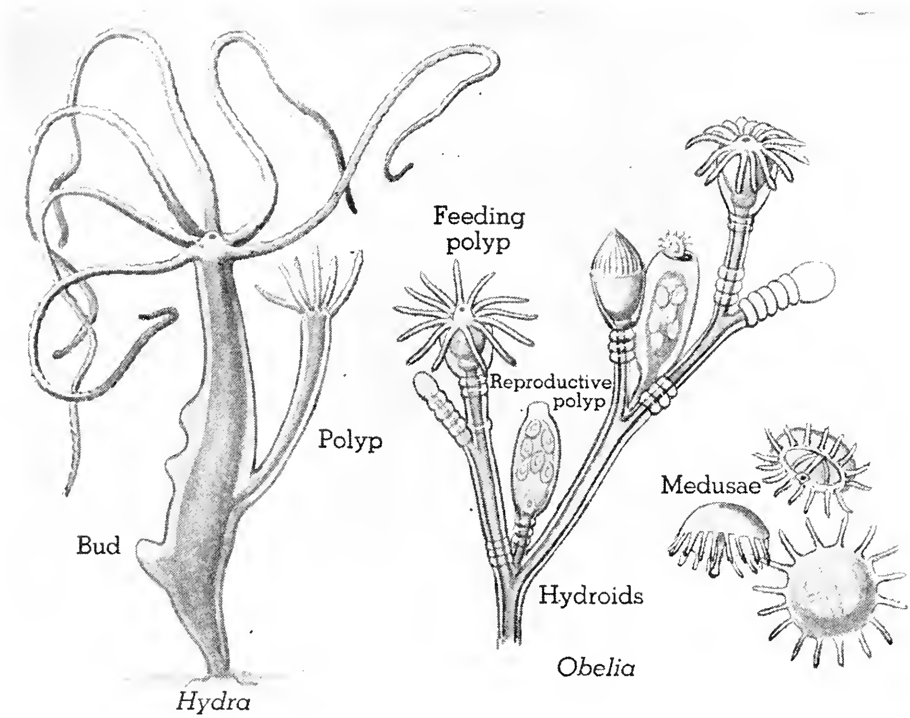
The egg, discharged into the body cavity, enters the Fallopian tube, carried along by movements of cilia on the lining cells. The egg meets the sperms and is fertilized inside the egg tube. The oviduct ends in the muscular uterus, within which the new individual develops

differ from each other as do male and female, for example. Indeed, this condition is quite general. It would be strictly true to say that many species are not merely dimorphic, or existing in two forms, sexually, but have three or even more "forms".

We saw that the Sporozoa reproduce by means of spores. In the case of the malarial parasite, for example, the spores are discharged into the plasma of the host's blood. If now a mosquito draws some of such infected blood, the stage of the parasite inside the mosquito reproduces sexually; the protoplasm divides up into tiny structures which unite in pairs. The sexual and the asexual state alternate so long as the parasite can get into a mosquito, then into a warm-blooded host, into a mosquito again, and so on (see page 622).

Is There Alternation of Generations in Plants?

The Life History of the Moss In the common species of mosses, the familiar green plants with small leaflets are male and female plants. In addition, there is a generation that reproduces by means of spores. Among the



TWO KINDS OF GENERATIONS

The hydra and its relatives reproduce by budding and also by means of gametes, which are discharged into the water. In the common salt-water jellyfish Obelia, there is a sexual generation, called the "medusa", which is quite distinct from the vegetative generation

leafy scales at the tips of some individuals flask-shaped structures develop. These produce a single egg cell each, and are called *archegonia*. In other individuals the corresponding structures produce large numbers of swimming sperm cells; these club-shaped organs are called *antheridia*. When the moss is covered with water, usually in the spring, the antheridia burst open, and sperm cells swim into the archegonia, where one fuses with each egg. The fertilized egg immediately begins to develop into a new individual, but this new plant is quite different in structure and appearance from either the male or the female parent. It consists of a bare stalk which forms a capsule at the tip—the spore capsule. Its base digs into the top of the mother-plant, from which it derives most of its nourishment (see illustration, p. 412).

When a moss spore alights on a suitable place, it absorbs water and puts out a thin thread of protoplasm. This develops chlorophyl and looks like one of the simpler algae. Later a clump of cells forms a sort of bud from which the vertical leafy stem grows into either a male or a female moss plant. In

such species the spore-bearing generation gives rise—through the spores—to a sexual generation. The sexual generation reproduces—by means of the gametes—and gives rise to a spore-bearing generation. There is thus a regular alternation between spore-bearing and gamete-bearing generations. These two generations are called *sporophyte* and *gametophyte* respectively—that is, spore plant and gamete plant.

Among the common ferns there is a similar alternation of generations. The familiar stage, with green fronds and usually a distinct underground stem, is the sporophyte (see illustration, p. 387). The spores, produced in tiny capsules on the under surface, are widely scattered by the wind. When a spore germinates, it gives rise to a flat somewhat heart-shaped plate of green cells, known as a prothallium—that is, a *pro*thallus or a thallus that precedes (in this case, the fern plant). Unlike the moss, the gametophyte stage is *not* dimorphic; the prothallium bears both archegonia *and* antheridia. The sperm cells swim in water. The zygote develops into the familiar fern sporophyte.

In What Ways Are Males and Females Different?

The Two Kinds of Gametes In the simplest of plants and animals, such as *Spirogyra* and *Paramecium*, we cannot distinguish the vegetative, or growing, stage of a cell from the reproductive stage—except at, or just before, the time of conjugation. Nor can we distinguish the passive, or receiving, gamete from the active, or supplying, gamete except in their behavior at this time: one moves and the other remains in place. As we pass on to more complex forms, the difference becomes more pronounced.

The swimming sperm cells of the bladderwrack and of other large algae, as well as of most animals, are decidedly active. They often have very distinct swimming cilia, or flagella, as well as shapes that suggest movement through water. In fact, when cells of this type were discovered by microscopists, from the time of Leeuwenhoek down past the middle of the nineteenth century, they were described as "new species" of "animalcules".

We can easily observe size, shape, food content, movement. Underlying these differences between the male and female gametes, we must assume others that are related to differences in their behavior. As sperm cells swarm about restlessly, they seem to turn definitely toward any egg of the same species that may be in the vicinity. We know that the eggs of certain plants influence the sperms through some chemical peculiar to the species. But when one of the active male gametes penetrates the egg membrane, something happens instantly; for all the others immediately swim away as if they had suddenly lost interest in the egg. But at the moment that the sperm enters, the egg actually forms a membrane through which no more sperms can enter. In any case, the fertilized egg does differ from the female gamete chemically.

In one respect male and female gametes are alike. Both have the same number of chromosomes, and this number is half that found in the tissue cells of the same species (see illustration, p. 388). Now the chromosomes are evidently related to the qualities or characteristics developed by the new individual. It is probably true, as Hertwig surmised about seventy years ago, that the mother-cell and the father-cell contribute in equal measure to the constitution of the offspring (see page 374).

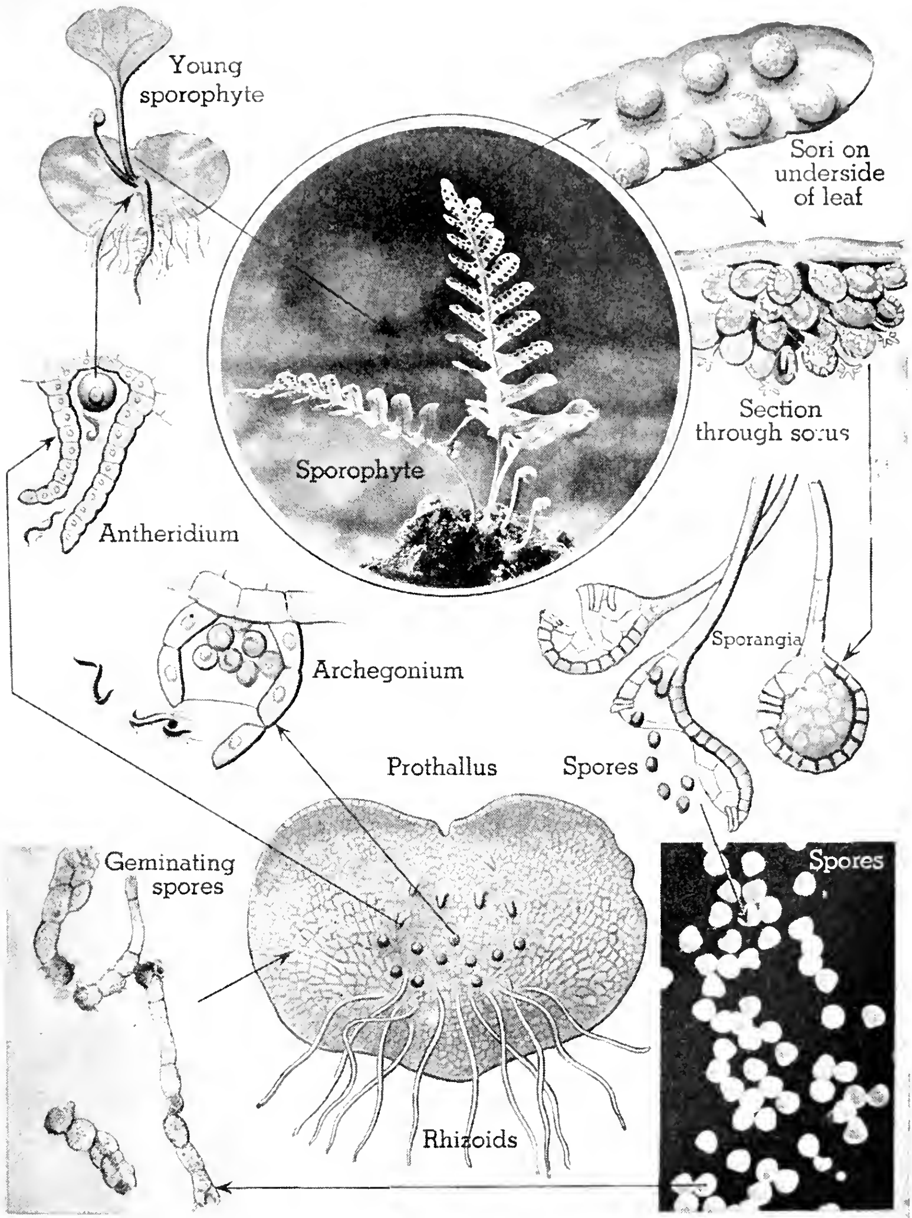
From Water to Land As we compare different classes of plants or different classes of animals, from the simplest to the more and more complex, we find the male and female gametes increasingly different. Moreover, the organs that bear the two kinds of gametes, and various accessory organs and structures, also become more and more differentiated.

When the egg and sperm unite during fertilization, their chromosomes combine, so that the zygote has the number "normal" for the species, called the *diploid* or double number. In distinction from this, we speak of the gametes having the *haploid* number (from a Greek word meaning "single").

In the mosses, for example, the male plant and the female plant look very much alike, except for the archegonia, or egg-organs, and the antheridia, or sperm organs, formed at the tip of the leafy gametophytes. After fertilization, which takes place inside the archegonium, the new individual grows out from the tip of the mother-plant, upon which it depends for nourishment. This new individual, as we saw, is a sporophyte, and it has the diploid, or double, number of chromosomes in its cells.

Among the ferns (which attained the size of great trees in former times) and among the seed-bearing plants, the familiar and conspicuous generation is the sporophyte, or spore-bearing, stage. In such types fertilization still takes place in water, although the plants seem to be high and dry above the soil. In most species of ferns the sexual generation, or prothallium, is rather inconspicuous (see page 387). In fact, Linnaeus classed all seedless plants as "cryptogamous"—that is, having hidden, or secret, marriage. That means merely that in his time we did not know how conjugation, or fertilization, takes place in the nonflowering plants, and we had only some guesses in regard to the seed plants. Although we consider the ferns farther advanced than the mosses, we find that both the egg-organs and the sperm-organs are borne on the same individual. As we come to the more complex flowering plants, however, maleness and femaleness become more sharply differentiated. Yet the gametophyte, or sexual, generation is so far reduced—especially in contrast with the sporophyte—that we have found the actual structures and processes only in modern times.

Among some of the lower orders of animals there are many species in which each individual bears both eggs and sperms. Such animals are sometimes spoken of as *hermaphrodite*, after a mythical Greek character having both



Hugh Spencer

LIFE CYCLE OF A FERN

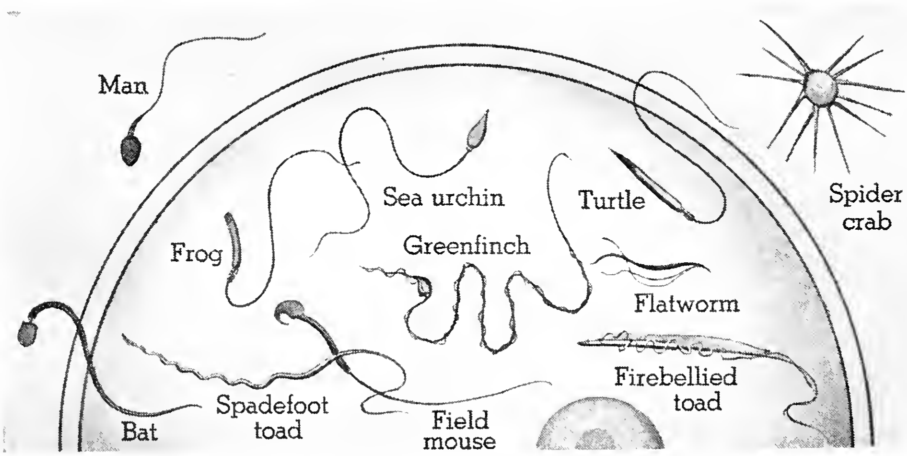
The fern plant that we commonly notice is a sporophyte. It produces spores which develop into gametophytes. The fertilized egg always gives rise to a sporophyte. The alternate generations reproduce in different ways—one by means of gametes, or sexually, the other by means of spores, or asexually

male and female traits (from *Hermes* and *Aphrodite*). In common earthworms, for example, each individual bears both ovaries and spermaries. But no individual fertilizes its eggs with its own sperms. There is an exchange of seminal fluid between two individuals, and the eggs of each are fertilized by sperms received from the other.

The common oyster of the northern Atlantic coast is interesting in this connection, since each individual is both male and female—but not at any one time. A female oyster will produce a large number of eggs, which are discharged into the water, where they are fertilized by sperms from other individuals. After a time, the ovaries become inactive and spermaries develop. Each individual periodically reverses its sex.

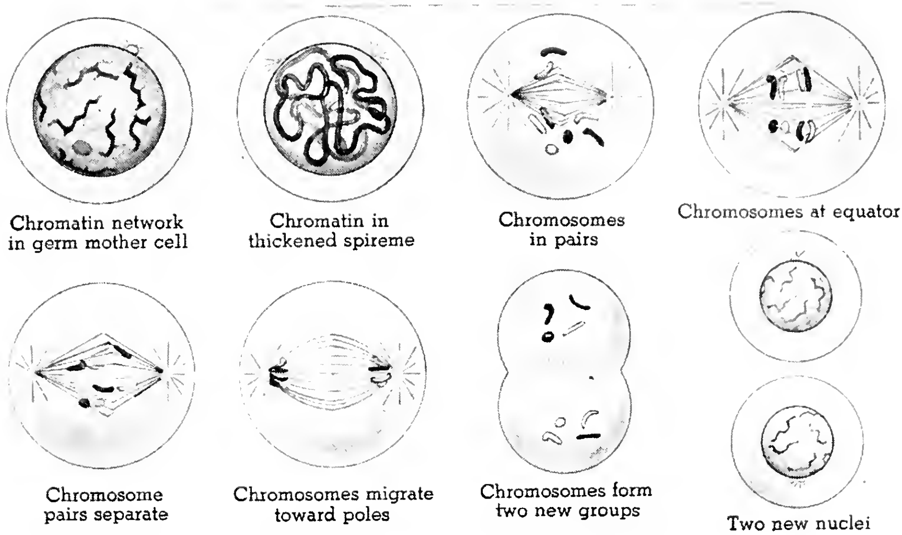
Primary Sex Characters In countless varieties of plants and animals reproduction consists only in the fusing of two unspecialized cells into a zygote. Biologists have therefore come to apply the terms *male* and *female* primarily to the gametes and to the special organs that produce these specialized reproductive cells. A male individual is thus one that bears sperms; a female, one that bears eggs.

Maleness and femaleness were generally taken for granted in familiar animals, but in ancient times it was commonly believed that there could be no sex in plants. Farmers and gardeners and fruit-raisers, however, knew from very ancient times that it is the flower of the common plants that produces the fruit and seed. They knew also that merely bearing flowers and having



MALE AND FEMALE GERM CELLS

The female gamete is usually spherical and inert, or passive, containing a great deal of nutrient material in proportion to its living protoplasm. The diameter of the human egg is about four times the length of the sperm, which means that it is many thousand times as large in volume. Sperm cells are typically ciliated or flagellated, and they swim rapidly in all directions



THE FORMATION OF GERM CELLS

In the formation of gametes in plants and animals, the chromosomes of each pair become separated during one cell division. As a result, each germ cell finally has only half the number of chromosomes present in the body cells of the species

good healthy growth would not be sufficient to ensure seed. And they knew that flowers would fail to produce seed unless some of the powdery or sticky pollen, or flower-dust, gets onto a special part of the flower, the stigma (see illustration, p. 399). Yet Aristotle and other great thinkers rejected the idea that there could be "sex" in plants.

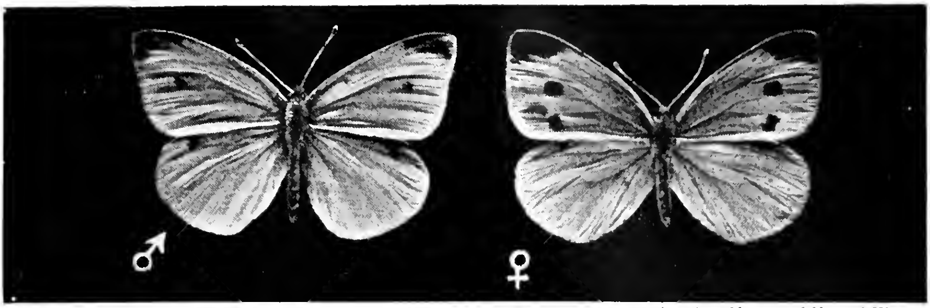
It was difficult to think of sex in plants, first for the reason that we commonly associate maleness and femaleness with two distinct kinds of individuals in most familiar animals. In addition, the familiar seed-bearing plants do not directly bear eggs or sperms. Although the experience of the race had established the fact that pollen somehow makes flowers capable of bearing seeds, it was necessary to wait for the microscope before anybody could know just what the connection is. So it came about that it was only about two hundred and fifty years ago that anybody did know just what the pollen has to do with the "setting" of seed. This was first worked out by a German botanist and physician, Rudolph Jacob Camerarius (1665–1721), who reported his discoveries in letters he wrote in 1694.

If we assume that the union of two cells is the essential fact about sex, it is interesting to note that some of the characteristics of the male and female gametes appear to be repeated and enlarged, or even exaggerated, in the entire organism. Maleness shows itself as movement, restlessness, a seeming drive to go places. We may recognize femaleness in a certain inertness, or remaining

The Metropolitan Museum of Art

THE RITUAL OF FERTILIZING THE DATE

The ancient Assyrians knew that the date palm never bears fruit unless the flower-dust of the "male" plant reaches the stigmas of the "female" plant. The king started the work of transferring pollen in a religious ceremony, which was recorded in stone tablets or monuments. Date-growers in California use essentially the same method systematically, but without ceremony. (Stone tablet from the palace of Ashur-nasir-pal II, king of Assyria, 885–860 B. C.)



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SEXUAL DIMORPHISM IN INSECTS

The cabbage butterfly, the female having two spots on the front wing, in addition to the dark tip

in place, in the absorbing of excess food which is normally passed on to the next generation. And there is almost uniformly a marked difference in size between the male structures—or even individuals—and the female, the female being generally the larger. Looked at from this point of view, maleness and femaleness seem to extend to many traits of plants and animals that are not directly connected with reproduction.

Secondary Sexual Characters We may see that in both plants and animals there are many characteristics which have nothing *directly* to do either with getting food and growing or with splitting off special reproductive cells—whether spores or gametes. In connection with producing and discharging eggs and sperms, some of these supplementary structures and processes seem to get far away from the essentials. We speak of such organs and activities as *secondary* sexual characters. The differentiations between male and female individuals are most striking and elaborate in flying animals—birds and insects. We can understand these as being in a way related to the fact that the gametes have to be brought together in a fluid medium. But

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SEXUAL DIMORPHISM IN CRUSTACEANS

Female and male of the fiddler crab, Uca brevifrons

American Museum of Natural History

SECONDARY SEXUAL CHARACTERS AMONG BIRDS

The drab female and gay male, African ostrich

some of these secondary sexual characters are found even among the water-inhabiting fishes and some of the crustaceans and other invertebrates, as well as in all classes of vertebrates (see illustrations, p. 391).

Here we see again a certain resemblance between maleness or femaleness in the individual and the special characteristics of the gametes. There is the roving disposition of the male, for example, as against the passivity of the female, or the contrasting aggressiveness and receptivity of the two sexes. These differences are associated in more complex animals with differences in nerves and muscles, in sense-organs and the effectors.

Among birds, we are impressed by the extravagant plumage of the peacock, in contrast with the plain garb of the peahen. In the bird of paradise and in the domestic fowl, the flashy dress and ornaments of the male are accompanied by show-off behavior and song. The spurs are related to a fighting temper. Among mammals, the males seem to go in for beards and ferocious-looking manes, for horns and large teeth. In many species there is a great difference in size between the sexes, the male being generally larger and more belligerent (see illustrations above and opposite).

The floral displays of seed-bearing plants and the specialized spore-distributing and spore-catching adjustments are so varied that they have occupied the lifelong study of many devoted scientists and nature-lovers. When the facts about seed-bearing plants are described, as they often are, by

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SEXUAL DIMORPHISM IN MAMMALS

Wapiti deer in Northern Colorado

poets rather than by scientists, we are made to see at once the resemblance between maleness or femaleness in plants and the corresponding characteristics of animals. And this in spite of the great differences between plant behavior and animal behavior, and in spite of the great differences in the matter of *feeling*, which is immeasurably more intense in the highest vertebrates than we can conceive it to be in other species of organisms. The flowering plants deserve at least a chapter for a survey (see Chapter 20).

In Brief

Unicellular plants and animals reproduce themselves by cell-division; their protoplasm is potentially immortal.

Cell-division is an essential feature of development, as well as of growth.

In multicellular organisms cell-division results in growth, in the healing of injuries, or in the regeneration of lost parts, and in the reproduction of new individuals.

Many species produce specialized cells, or spores, from which new individuals develop; these spores are capable of resisting unfavorable conditions almost indefinitely.

Many species produce specialized reproductive cells, gametes, which unite in pairs into zygotes; these, in turn, develop into new individuals.

The union of two gametes, a sperm and an egg, is the essential fact of sexual reproduction. It is called fertilization.

In the vertebrates, eggs, discharged into the body cavity by the ovary, pass through an oviduct before reaching the exterior; sperms, developed in the testes, also pass through a special duct to the exterior.

The distinctive variations in reproductive organs are related to the manner in which eggs and sperms are brought together and to the way the fertilized egg cell is nourished.

In the more complex species the gonads—the ovary of the female and the testes of the male—are both hormone-producing as well as gamete-producing organs.

Among mammals the embryo develops within the uterus until it attains a form distinctive of the species.

Many species of plants and animals produce vegetatively, as well as sexually.

Some species of plants and animals reproduce alternately by vegetative and sexual processes.

Among insects, as among reptiles, birds and mammals, fertilization takes place within the body of the mother.

At all levels of animal life the male gamete, or sperm, is motile; the female gamete, or egg cell, is passive and richly supplied with food.

The number of chromosomes present in gametes is half that present in body cells.

Most familiar plants, as well as animals, reproduce by forming male and female gametes, that is, sexually.

Among lower forms of animal life there are hermaphroditic species, that is, forms in which the individual bears both male and female gametes.

Parallel to the differences between the gametes, males are characteristically restless, roving, searching, aggressive; the females are passive, receptive, eventually directing their resources to the nourishment of offspring.

Characteristic differences between males and females which have no direct connection with reproduction are spoken of as secondary sex characteristics.

EXPLORATIONS AND PROJECTS

1 To study reproduction in the ameba, examine several specimens mounted under a cover-glass, with both low and high magnifications; watch for cell-division. Sketch different stages in the division. Try to distinguish the nuclei within. Describe the way the ameba reproduces.

2 To study reproduction in the paramecium, prepare slides having numerous individuals on them. Search for individuals that are dividing; follow one in the process of fission under low magnification until the process is complete. Note the length of time it takes. Compare the new individuals as to the oral groove and other structural characters that may distinguish them. Describe the type of repro duction in the paramecium.

3 To find out how mitosis, or cell-division, takes place, examine models or charts showing the several phases in mitosis. To see the various stages of division, study with the aid of a compound microscope prepared slides of sections of an onion root-tip, in which cells reproduce rapidly. Draw and describe the essential facts in mitosis.

4 To demonstrate regeneration in plants, propagate plants vegetatively by means of cuttings, tubers, bulbs, corms, rhizomes, runners, budding and grafting.[1] Make cuttings from healthy plants with a sharp knife and place in moist-sand flats. After roots have formed, transfer new plants to good soil. Transplant tubers, bulbs, corms, parts of rhizomes, or buds from runners directly into good soil. Compare these modes of producing new individuals with the regeneration of new individuals from fragments of flatworms. Compare the new plants produced by these vegetative means with the original plant from which the organs were removed.

5 To find out how mold reproduces, grow a rich colony and examine parts with the microscope.[2] Examine threads and sporangia with low power and with high power. Place spores on a sterile agar plate, or in a 1 per cent sugar-solution on a slide, or in some other suitable medium, to find out whether they are capable of producing new mold plants. (Keep in a warm, moist place for a few days.) Watch for new threadlike growths emerging from single spores. Describe this method of reproduction.

6 To study the egg-laying organs of a hen, dissect out the single left ovary and oviduct and examine carefully. Describe the essential structures. Where does fertilization probably take place? Describe the reproductive process in poultry.

7 To see viviparous reproduction in fish, grow guppies under observation in the laboratory. (The larger fish is the female. When her body becomes swollen, watch for the very small young to be born. Remove the young immediately to

[1]For cuttings use willow, forsythia, privet, geranium, coleus or begonias. For tubers use potatoes, cinnamon vines or Jerusalem artichokes. For bulbs use tulip, onion, hyacinth or lily. For corms use gladiolus, spring beauties or trilliums. For rhizomes use bluegrass, iris, rhubarb or yarrow. For runners use strawberry or cinquefoil.

Farmers' Bulletin No. 1567, *Budding and Grafting*, gives detailed information on procedures. Different varieties of apple can be grafted onto one tree. Apple, pear and quince can be grafted onto one another; peach and plum may also be grafted on each other. The cambium layer of the cutting, called the *scion*, must come in contact with the cambium layer of the stock to which it is being grafted. In doing cleft grafting apply dormant scions to stock before the buds begin to swell. Seal cuts with grafting wax.

[2]To grow mold, expose a slice of bread to the air for ten minutes for some mold spores to fall on it. Keep in a warm place on moist paper on a plate, covered with a jar or tumbler. In a few days black dots (the "fruit-dots", or sporangia) will be seen scattered in the white fuzzy growth.

another aquarium, as the mother fish may soon eat the young.) Compare this method of reproduction in fish with that observed in most other fishes. Note the probable mode of fertilization in these viviparous fish.

8 To study the reproductive organs of frogs, dissect freshly killed male and female frogs; locate, examine and describe the spermaries, sperm ducts, ovaries and oviducts. Note the large size of the ovaries and oviducts. Count the eggs in a portion of the ovary and estimate the total number in one female frog. From the study of the internal organs describe reproduction in frogs.

9 To find out how the fetus of a mammal develops within the uterus of the female, dissect a pregnant guinea-pig, rat or rabbit late in the gestation period. Note the stretched and enlarged uterus. Find the sac within which each fetus is located. Note how the placentas are embedded in the uterine wall. Describe mammalian reproduction.

10 To investigate the reproduction of the hydra, examine living specimens under low magnification,[1] identify buds in various stages and find individuals with developed sex organs. Describe the methods by which hydras reproduce.

11 To discover the reproductive organs of moss plants, use living male moss plants which are distinguished by a cup-shaped tip, female moss plants, and female moss plants with sporophytes attached. Place the tip of a male plant in a drop of water on a slide, and with a stirring motion of a dissecting needle tease out the antheridia (club-shaped organs bearing sperms). Remove the scales from the tip of a female plant and then dissect out the archegonia on a slide with a needle. Examine the base of a sporophyte and its attachment to the tip of the female, or mother, plant. Examine spores from the capsule at the end of a stalk. Crush a sport capsule over the surface of a dish of diluted Knop's solution[2] and set aside for the growth of new individuals. Describe and illustrate methods of reproduction in mosses.

12 To study reproduction in ferns, grow prothallia from fern spores and observe microscopically from eight to ten weeks later.[3]

While prothallia are developing, examine under surfaces of leaves for the sori, or clusters of sporangia. Crush sporangia on a slide and examine them and discharged spores with microscope.

Look for antheridia and archegonia on under surfaces of fern prothallia (archegonia just behind the notch; antheridia farther back). Mount prothallium on slide and look for sperms swimming in the water.

[1]Hydras can frequently be found on the sides of aquariums set up months earlier with plants, snails, insects, and pond water collected locally. Cultures of living hydras can be procured from biological supply houses.

[2]Knop's solution consists of 1 g each of potassium nitrate, magnesium sulfate, and potassium phosphate, and 3 g of calcium nitrate dissolved in 1 liter of distilled water. Dilute to $\frac{1}{3}$ strength to grow protonemata of moss.

[3]Collect mature leaves of polypody, shield, or Christmas fern, with sporangia; dry in dustproof boxes for a few days. Fill a thoroughly cleaned 3-inch or 4-inch flowerpot with sphagnum moss or wet toweling; invert in a wet tray and dust fern spores on it; cover outfit with inverted battery jar. Place culture in a cool place under moderate light. Water with diluted Knop's solution. Germination should occur in a few days, and prothallia should mature in from eight to ten weeks.

Describe the two methods of reproduction in ferns. Note ways in which they are alike and ways in which they are different. Note conditions under which each takes place. Compare reproductive stages and structures of the fern with those of the moss.

QUESTIONS

1 In what different ways do unicellular plants and animals reproduce?

2 How does reproduction in one-celled plants and animals differ from that in many-celled ones?

3 In what ways do familiar plants reproduce vegetatively?

4 Why do we prefer to multiply many domestic varieties of plants by vegetative methods?

5 What different kinds of specialized reproductive cells are formed in plants?

6 How do gametes act in reproduction? How do male and female gametes differ from each other?

7 What are the relative advantages of the mammalian method of reproduction? the disadvantages?

8 In what main groups of animals are male and female individuals distinct from one another?

9 In what groups of organisms are individuals male and female?

10 In what groups of animals does the sex vary periodically or with external conditions?

11 What are the stages in the alternation of generations in moss plants? in fern plants?

12 In what respects is reproduction in ferns more advanced than in mosses?

13 In what groups of animals does fertilization take place within the body of the female?

14 What are the relative advantages of fertilization within the body of the female?

15 How does the number of chromosomes in the gametes compare with the number in the tissue cells?

16 What in addition to the gametes do the gonads of the more complex species produce? How do the gonads influence development?

17 What are the secondary sex characteristics of familiar birds and mammals?

1 Can flowering plants reproduce in any other way than by seeds?
2 Can any plants produce seeds without flowers?
3 How does pollen act in a flower?
4 Are the eggs of all flowering plants fertilized inside the flower?
5 Is there anything in animals to correspond to seeds?
6 Is there anything in plants to correspond to the egg of a bird?
7 Do any animals depend upon other species in reproduction, as flowering plants depend upon insects?
8 Is there anything in animals to correspond to pollen?

By far the most varied in the number of species, and certainly the most complex, are the flowering, or seed-bearing, plants. Some of them live but a few weeks of summer weather; others grow to be hundreds of years old. And they have spread all over the habitable earth. These plants are typically stationary, firmly rooted in the soil, in contrast to land animals, which move about freely. Yet they manage to bring about sexual reproduction between individuals far apart, and to spread their offspring out in all directions ahead of the free-moving animals. They manage to capture various natural movements that go on about them, both animate and inanimate, just as they have captured the energy of sunlight through their chlorophyl.

In their formation of gametes, and especially in the mechanism by which two gametes are brought together, the flowering plants present an amazing and fascinating variety of forms and structures.

In What Ways Are All Flowers Alike?

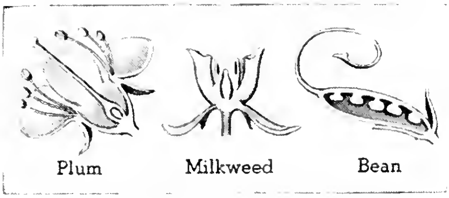
The General Idea of a Flower[1] Almost anything on a green plant that is not green catches the attention. There are many leaves and other growths that arrest the eye; but a *flower* is a highly specialized structure. Flowers range in size from an eighth of an inch or less across to perhaps a yard or more. They differ also in shape and relative numbers of parts, as well as in colors. And they differ in their arrangement—in relation to the leaves and in relation to one another on the stems of a plant (see illustrations, pp. 12 and 31).

The essential organs in all flowers are those that have to do with producing seeds. The seeds originate from tiny structures called *ovules*, or "little eggs", which are borne in special organs at the center of the flower, called *carpels*—from a Greek name for fruit, *karpos*.

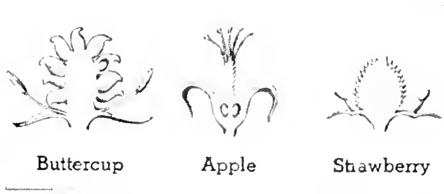
The single carpel of a flower, or the structure formed by the carpels fused together, is sometimes called a *pistil*, from the fancied resemblance to the

[1]See No. 1, p. 414.

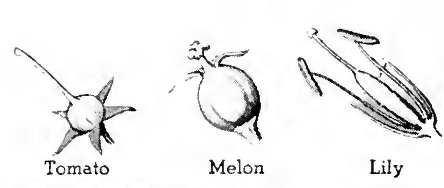
In some species each flower has a single carpel, as in



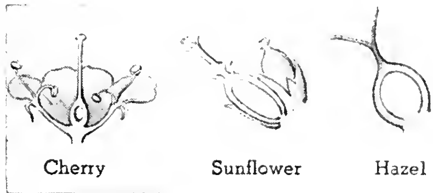
In other species each flower has several carpels, as in



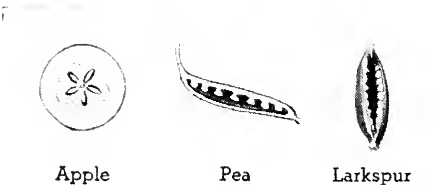
The two or more carpels in a flower may be quite distinct, as in the columbine and strawberry, or they may be more or less fused, as in



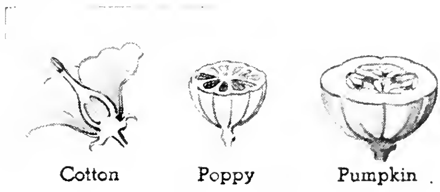
Each carpel may contain a single ovule, or seed, as in



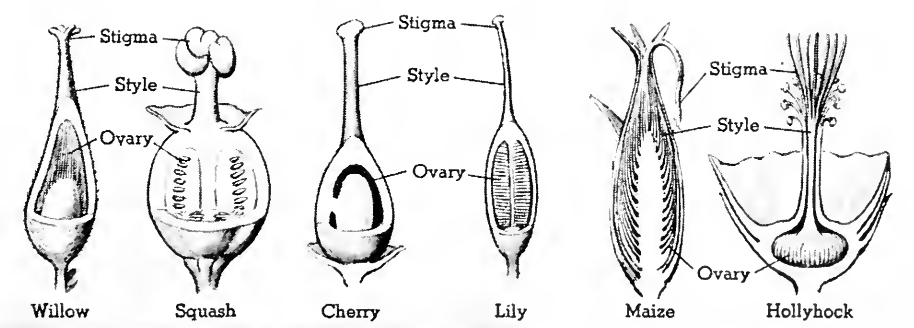
Each carpel may bear several ovules, as in



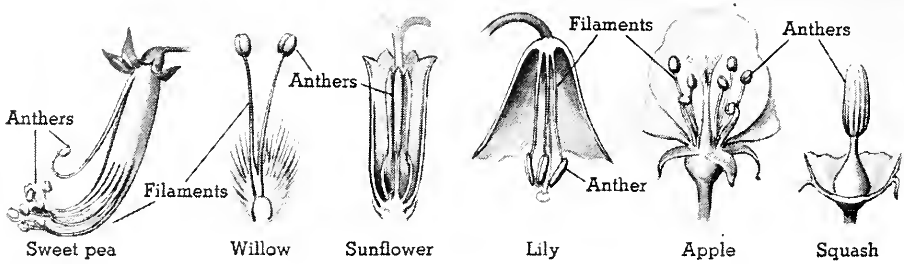
Or each carpel may bear very many ovules, as in



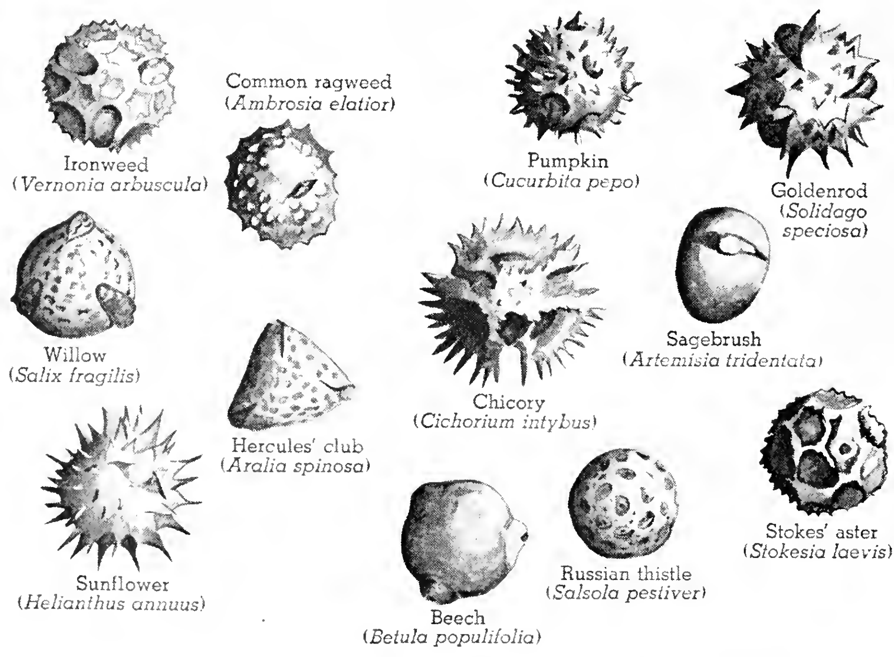
apothecary's pestle (see illustration below). The enlarged portion, which encloses the space that bears the ovule or ovules, is called the *ovary*—the same name as that given to the egg-bearing organ in animals. Where the pistil consists of several carpels, the ovary is often divided into as many compartments. The tip of the pistil is called the *stigma*, meaning "spot", and it plays an important role in the reproduction of the plant.



Seeds are borne in the ovary. The stigma may be close to the ovary or separated from it by a longer or shorter stalk, the style. The stigma may be simply a rough or sticky surface, or it may be a lobed, hairy, or sticky expansion.



Surrounding the pistil, in most common flowers, are a few to very many slender stalks with enlarged ends, called the *stamens*, from a Latin word meaning "thread". In some species, however, the stamens and pistils are in different flowers, or even on different individual plants. The enlargement at



POLLEN GRAINS[1]

[1] After *Pollen Grains*, by R. P. Wodehouse, copyright McGraw-Hill Book Company.

the end of the stamen is the pollen box, or *anther*, from a Greek word for flower. The anthers bear sticky or powdery pollen grains, which correspond to the spores of simpler plants.

The pollen grains resemble the spores of various kinds of simpler plants, such as mosses and ferns (see illustration, p. 387). And like such spores they normally give rise to a structure that corresponds to a *gametophyte*, as in mosses and ferns (see page 385). But this is a very small plant that can be seen only with a microscope, and so is easily overlooked. Moreover, this gametophyte, which produces only a sperm cell and is therefore considered a male, carries on its activities for the most part within a flower; and its short life ends in fertilization.

The ovule contains a large cell which we take to correspond to a spore that gives rise to a *female gametophyte*. This completes its entire life as a parasite within the ovule. For these reasons the pistil is sometimes spoken of as the female organ of the flower.

Where the corolla is a cup or tube, we can usually make out a definite number of points or lobes, which we take to represent so many petals, as in


Morning glory


Potato


Sunflower

Where the petals are distinct, their number is usually definite for a particular class — three or four or five, or a multiple of the number — as in


Trillium


Mustard


Buttercup

In "double" or other cultivated plants, like dahlias, the number of petals may be very great, as in


Rose


Water lily


Peony

Outside the corolla a group of greenish, leaflike parts form a cup or calyx, as in


Buttercup


Pea


Apple

In some families of plants the calyx is hardly distinguishable from the corolla, as in


Star grass


Tulip


Dogtooth violet

And in many species of trees and grasses the envelope is inconspicuous or entirely absent, as in


Willow

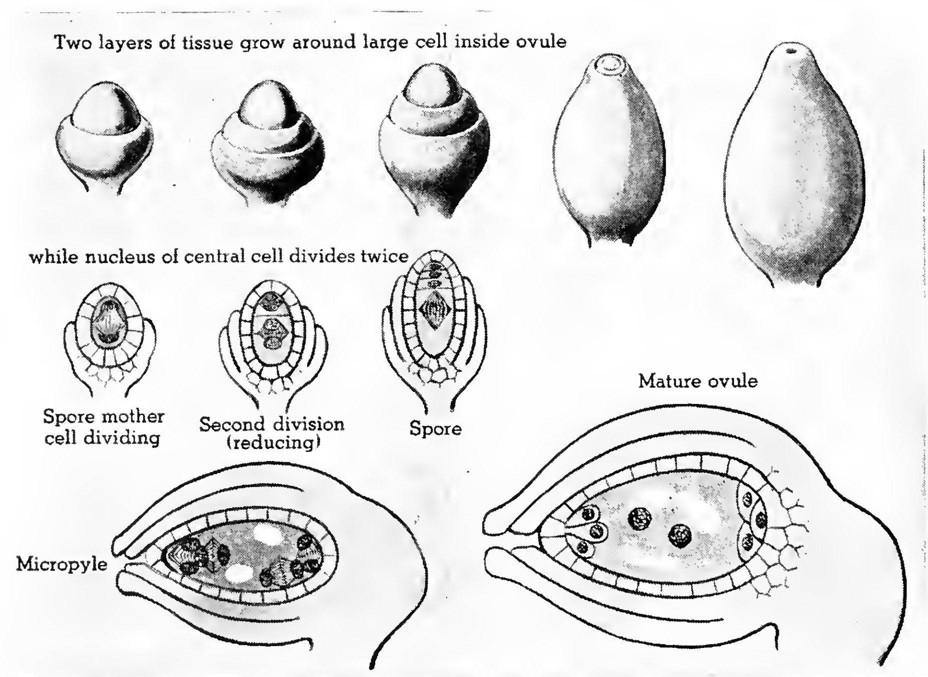

Oak


Orchard grass

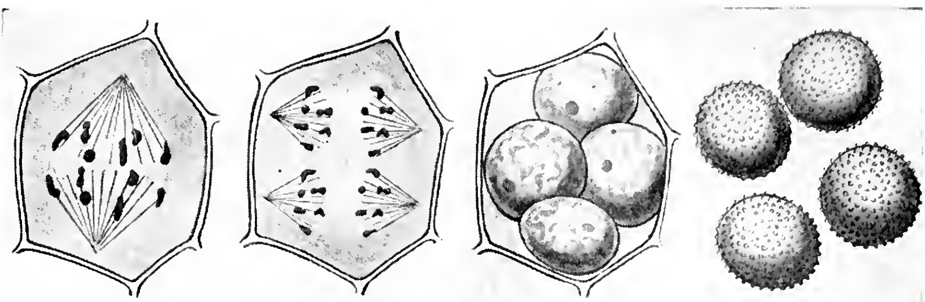
Accessory Organs of Flowers Surrounding the stamens and pistils in all the familiar flowers is a ring of colored or white leaflike structures that make up the *corolla*, or "crown", of the flower. The separate parts are called *petals*.

The Ovule as a Female Organ As the ovule develops, two layers of tissue grow around the large cell on the inside and finally enclose it, leaving a small opening at the end. In the meantime, the nucleus of the central cell undergoes two divisions, the second division leaving the number of chromosomes reduced by half (see page 385). One of the nuclei enlarges and crowds the three others to one end, where they eventually die. The enlarged cell with its haploid nucleus is called the *embryo sac*.

We saw that the reduction in the number of chromosomes is characteristic of the formation of sexual reproductive cells. The embryo sac, however, despite its haploid nucleus, is not a germ cell: it corresponds to a spore. Now the embryo sac nucleus divides, and the new nuclei divide further several times. The haploid nuclei resulting rearrange themselves, but no cell walls are formed. One of these nuclei becomes the female gamete and moves toward the end of the embryo sac near the opening in the ovule. Other nuclei later take part in the complex processes that accompany fertilization and the early stages of development. They seem to be related to the nourishment of the fertilized egg and the young embryo.



THE OVULE AS A FEMALE ORGAN



THE ORIGIN OF POLLEN GRAINS

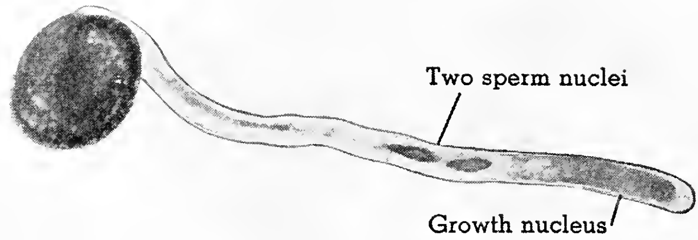
In the pollen mother-cell the nucleus undergoes two divisions without the formation of cell-walls. In one of the divisions the chromosomes are reduced to half the normal number. Around each of the four nuclei a thickened cell-wall is formed. This more or less rounded cell becomes separated from the others and is a pollen grain

What the earlier gardeners and biologists did not know, and could not know until certain microscopic studies had been made, is that in "fertilization" a haploid nucleus from a pollen grain gets into the embryo sac and fuses with the particular haploid nucleus which we have called the "egg", or female gamete.

The Anther as the Male Organ With the help of a microscope we can distinguish inside an anther the cells that are to produce pollen grains (see illustration above). These pollen mother-cells contain dense, granular protoplasm. In each mother-cell the nucleus divides, and each new nucleus divides again, but no cell-walls are formed. In either the first or the second division, varying with the species, the number of chromosomes becomes reduced to the haploid number (see page 386). The four haploid nuclei become separated, and a thickened wall is formed around each, with its cytoplasm.

In the formation of these "male spores" the mother-cell gives rise to four spores. In the formation of the embryo-sac nuclei, the original mother-cell gives rise to only one female nucleus, the other three disappearing. However, the protoplasmic material is not destroyed, but becomes organized around the single female nucleus.

We see, then, that in flowering plants the male and female gametophytes are reduced to single cells. Yet inside these cells very complex activities take place, leading to the formation of a single gamete in each case—the male and the female.



POLLEN TUBE

Under suitable conditions, pollen grains sprout like spores, the protoplasm growing out into a long thread. The haploid nucleus in the pollen divides into two. One of the nuclei seems to direct the growth of the tube. The other divides again: these final nuclei are the true sperm, or male, cells

How Does Fertilization Take Place in a Flower?

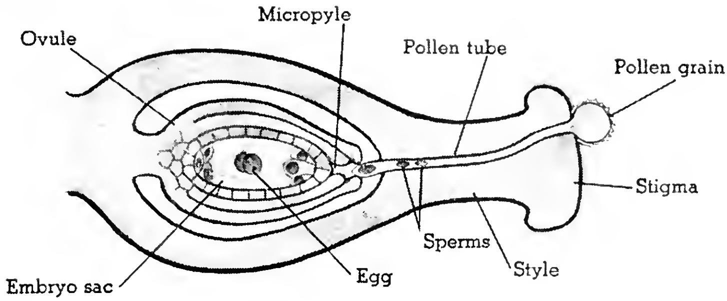
The Meeting of Gametes[1] In most common plants stamens and pistils are borne in the same flower. Fertilization is nevertheless brought about in a very roundabout way. The embryo sac remains inside the ovule, as the ovule remains inside the ovary. All the traveling is done by the pollen.

When the pollen grain alights upon the stigma of a pistil, it absorbs some of the fluid on the latter. Then a very thin thread of protoplasm grows out of the pollen grain—the "pollen tube". It is comparatively easy to get pollen grains of many different kinds to sprout their pollen tubes in a drop of sweetened water, on a microscope slide, and to observe some of the changes that take place (see illustration above).

The pollen tube normally grows through the style of the pistil into the hollow of the ovary. Then it grows through a small hole in the ovule that reaches toward the embryo sac (see illustration opposite). Pollen tubes appear to be chemotropic. When the tip comes in contact with the embryo sac, the cell-wall melts away, and the two sexual nuclei combine. This is the essential fact of fertilization. The zygote, having the double, or diploid, number of chromosomes, is the first cell of a new individual. It corresponds to the fertilized egg of a fern or moss—or, for that matter, of an animal.

The New Individual[2] After fertilization, the mass in the embryo sac absorbs food from the parent plant and grows into an embryo (see illustration opposite). The surrounding walls of the ovule become the seed coats. The ovule, with its embryo sac, thus changes into a seed. In addition to the

[1] See No. 2, p. 414. [2] See No. 3, p. 415.

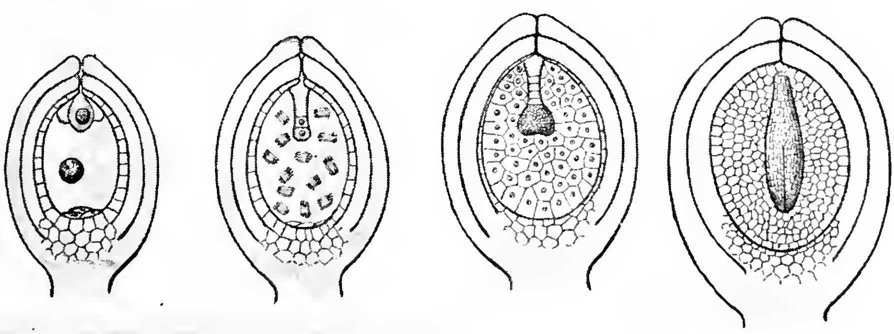


FERTILIZATION IN A FLOWER

A thread of protoplasm grows from the pollen grain on the stigma, penetrates through the style and through a little opening in the wall of the ovule. When the tip of the pollen tube reaches the embryo sac, a nucleus of the embryo sac and a nucleus of the pollen tube unite. This is the essential fact in fertilization

food used by the embryo as it grows to the stage of a ripe seed, other food materials are accumulated in the ripening seed. These reserves are either in the embryo tissues or immediately surrounding the embryo—in the so-called *endosperm.* After the seed sprouts, and before the young plant is ready to supply itself, the new individual lives on this accumulated reserve or surplus.

Fertilization brings about changes in other parts of the flower. The petals drop off or shrivel away, and usually the stamens also. The ovary begins to enlarge and at last ripens into the central or the main body of the fruit. In



THE EMBRYO OF A FLOWERING PLANT

The fertilized egg cell passes by a series of cell divisions into a mass that gradually takes on a definite form. In most species it becomes possible to distinguish the root, the stem, and the first leaf or leaves

some plants the calyx of the flower, and even the enlarged end of the stalk, the *receptacle*, may become fused into the fleshy fruit.

In most of the common plants the fruit will not ripen (that is, the ovary will not continue its development) unless fertilization takes place. But many plants ripen a seedless fruit; we have varieties of seedless oranges, seedless grapes and seedless apples. The pineapple and the banana are examples of fruits that develop without the ovule's being first fertilized. The plantain and the breadfruit develop a more juicy fruit when the ovary is not fertilized. In more recent times it has been found that ovaries of tomatoes and other plants can be stimulated to grow into fruit by means of chemicals related to the auxins (see page 258).

How Does Pollen Get to the Stigma?

Self-pollenation[1] In many plants the pollen is carried from the stamen to the stigma by the growth movements of the parts of the flower. The style, as it gets longer, may bring the stigma in contact with the anther. Or the corolla, as it grows and opens, pushes the stamen against the stigma. In some species the stalk of the flower may bend over as it grows, and so dumps some pollen from the anther onto the stigma. In some flowers the anther stands above the stigma, and the pollen is carried over by the action of gravity. Thus there are many kinds of plants in which the flower may be said to pollenate itself. This process is called self-pollenation and takes place in such varied flowers as

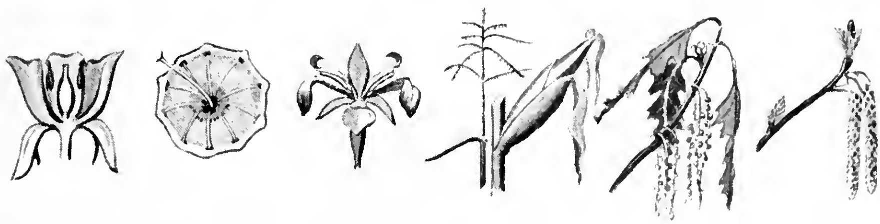
Round-leaved mallow Sweet pea Tomato Knotweed Wheat

Obstacles to Self-pollenation There are many plants, however, in which self-pollenation is quite impossible. In some species the stamens and the stigmas do not ripen at the same time; self-pollenation is then impossible. The pollen ripens before the stigma in maize, in the mallows, in many species of the aster family, in the creeping crowfoot, and in the sage. The stigmas ripen ahead of the stamens in the common plantain, in the potentilla, or cinquefoil, and in the Oriental grass known as Job's-tears.

[1]See No. 4 p. 415.

In some species stamens and pistils are so placed that the pollen cannot get to the stigma, as in

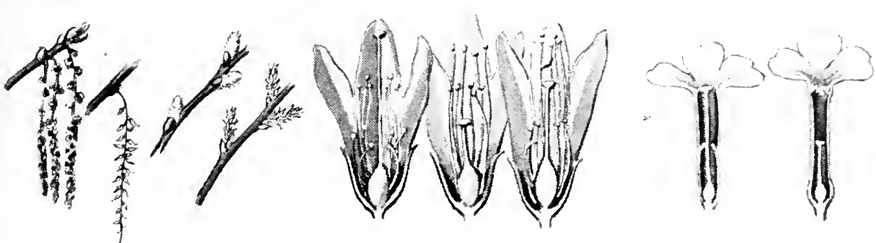
In many plants the stamens and pistils are borne on different flowers, as in pumpkin and in



Milkweed Kalmia Iris Corn Oak Birch

In some species of plants the staminate flowers are borne on one individual and the pistillate flowers on another, as in

In some species the flowers are in two or three forms, with the anthers in one matching the relative position of the stigmas in another, and pollen acts only on stigmas of corresponding height, as in



Aspen Willow Purple loosestrife Primrose

In some species of plants, if the pollen gets to the stigma of the same flower, it will not lead to fertilization. The pollen will in some cases result in poorer seeds than those produced by means of pollen taken from another flower. But in buckwheat, in most orchids, in certain species of day lily, and in some members of the bean family the pollen will not even put out a tube if placed on the stigma of the same flower.

Cross-pollenation Plants that cannot pollenate themselves depend upon outside moving bodies to transfer the pollen for them. The most common moving agency is the wind. That the wind is an effective agent in pollenation is seen in the amount of pollen present in the dust at certain seasons of the year (see illustration, p. 408). Corn, wheat, oats, grasses generally, many of the common trees, as well as many other plants, depend entirely upon the wind for their pollenation. Another effective agent in distributing pollen for plants is moving water. This is illustrated by the tape-grass, or eel-grass (*Vallisneria*), which lives near the edges of ponds. The pistillate individuals of the eel-grass grow up to the surface of the water, where the flowers open. The staminate individuals remain below; the closed flowers become detached

Rutherford Platt

Single Flower of Elm, Magnified

Staminate Catkin of Birch

THE DISTRIBUTION OF POLLEN BY WIND

The rather dry pollen of our common trees is shed from the stamens in vast quantities and scattered widely by the wind

and float to the surface in large numbers. Here they open, and as they come in touch with the exposed stigmas, the pollen is transferred directly.

Next to the wind, the most common moving agents that pollenate flowers are flying animals, like species of birds and insects that regularly visit flowers. Certain tropical flowers are said to be pollenated by bats that come to them for nectar.

In thousands of species of plants the flowers are pollenated by insects, chiefly varieties of bees and wasps and certain moths and butterflies. All these insects have sucking mouths, and they all visit flowers that contain nectar. Some of these insects also use pollen as food. In gathering the pollen or in sucking nectar the insects rub off pollen on various parts of their bodies; and when they visit other flowers of the same kind, they then transfer the pollen to the stigmas (see illustration, p. 410). Many species of flowering plants, especially among the orchids, depend so completely upon particular insects that they produce barely enough seeds to maintain themselves.

Flowers as Secondary Sexual Structures We saw that among many species of animals males and females differ from each other strikingly in details that are only remotely or not at all related to the formation of gametes or to their conjugation. The flowers that are often so highly specialized in the struc-

ture, coloration, and odor of their envelopes may also be considered secondary sexual characters. They are certainly related to reproduction, and especially to bringing pollen near the embryo sac. Yet they cannot be considered specifically male or female, since in most flowers both functions are carried on.

Like some of the display features in animals, floral colors, shapes, odors, nectaries, may be said to "attract". But they attract chiefly insects rather than pollen. On the other hand, the sticky or fuzzy stigma of many flowers is well adapted to catching and holding any pollen that does come by, whether brought by insects or by the wind.

Another interesting fact about the flowers is their presence only in sporophytes—that is, plant generations that bear asexually produced spores. The envelopes of flowers and the other accessory structures are nevertheless related to sexual reproduction, like the secondary sexual characteristics of animals. And we may consider such structures, in both plants and animals, as elaborations of extras, or "luxuries", which are possible only when a species has become so efficient that it can draw upon a great deal of reserve or surplus food.

How Do Plants Scatter Their Seed?

Seeds and the Species[1] During the winter the trees and shrubs are bare. But millions of other plants perish entirely. Of thousands of species, nothing remains alive except the hard and inert seeds. It is through their seeds that these species will renew themselves when conditions again make growth possible.

In the life cycle of a seed-bearing plant, the fruit is the organ within which the seed originates and ripens. We may consider the great variety of fruit forms as related to the protection of seed against possible enemies and dangers—including the danger of remaining right at home. Seeds that are enclosed in edible fruits are often distributed by animals that eat the fruit and then discharge from their intestines the uninjured seeds, as in many berries, viburnum, and cherry.

Many fruits open so suddenly, usually by a twisting of the parts of the pod, that they shoot the seeds to a distance of a yard or more, as in squirting cucumber, lupins, and monkshood.

Most plants depend upon outside agencies to scatter their seeds for them, as they do for the distribution of pollen. Seeds that are very small, or that have expanded winglike surfaces or tufts of hairs, are scattered by the wind, as in milkweed, clematis, thistle, cottonwood, elm, maple, and linden.

Such fruits or seeds cannot be said to fly, like airplanes or birds—or even to glide, for they are carried without goal by the winds of chance.

Some fruits have hooks which catch in the fur of passing animals and are

[1]See No. 5, p. 415.

Inez McCombs, based on photograph by Rutherford Platt

INTERDEPENDENCE OF INSECT AND FLOWER

The bumblebee and the lobelia seem to fit one another in size and in the arrangement of parts, and to serve one another in their behavior. The insect, going about its business in one flower after another, leaves on each stigma some of the pollen that has clung to its hairy body

carried considerable distances, as in cocklebur, sandbur, tick trefoil, cosmos, and Spanish nettle.

From Generation to Generation When we think of the lowest plants and animals, we cannot make a sharp distinction between parents and offspring. In the simplest organisms, as we have seen, a whole life span is included between one cell-division and the next. During this lifetime there is very little change in structure: the youngest resemble the oldest in almost everything but size (see illustration, p. 10). The "mother" cell goes out of existence at the moment the "daughter" cells come into being: parents and offspring cannot exist at the same time.

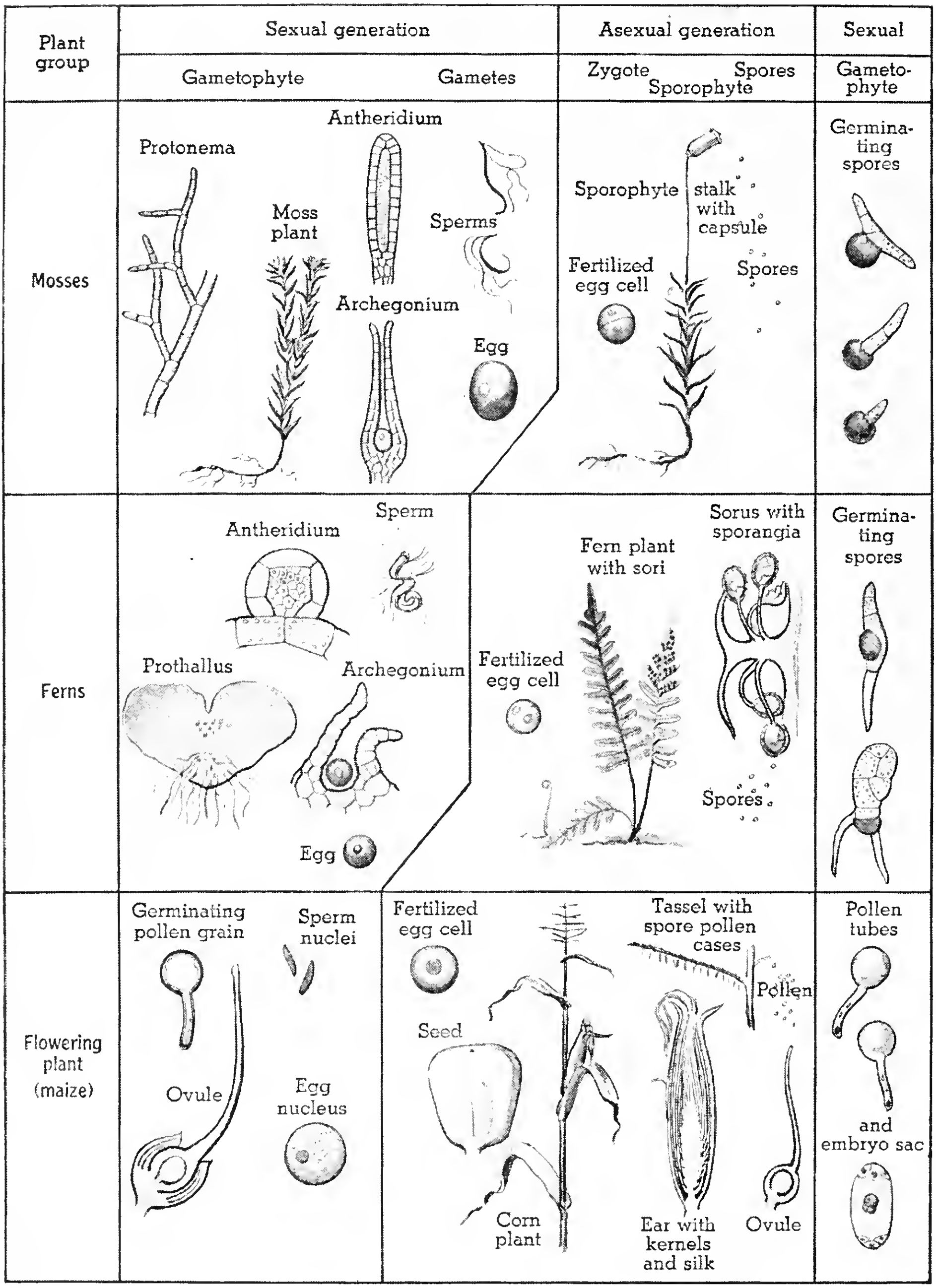
Among the larger seaweeds the expanding vegetative plants bear special reproductive organs on some of their branches, and discharge tremendous numbers of eggs and sperms into the water. For every pair of gametes that conjugate, thousands are destroyed. For every zygote that starts a new individual, thousands are destroyed. The mosses and ferns retain the female gamete within the body of the parent until it is fertilized.

In many species of mosses each green gametophyte ripens but a single egg, and then it nourishes the nearly parasitic sporophyte to maturity. But then one sporophyte discharges thousands of spores (see page 387). The ferns seem about to have solved the problem of living on dry land. The sporophyte has come to be the prominent generation, with expanded green foliage, with stems having definite conducting vessels and mechanical structures, and with fairly good roots. The gametophytes, as we have seen, are flat little plates of cells (see illustration, page 387). These plants depend upon a wet season only for the short period during which the sperms swim out and reach the egg cells. The fertilized egg starts out well nourished within the body of the gametophyte. The expansive sporophyte contributes to the species a vast number of spores, with the chance that the wind will carry a few to spots favorable to starting new gametophytes (see illustration, p. 412).

Infancy in Seed Plants[1] Among the most complex plants, structures and behavior seem to be still further adapted to the advantage of the species. Spores are produced in relatively small numbers. The gametophytes are trivial, one-celled structures that remain dependent upon the parent sporophyte. It is through the structures of the sporophyte that pollen spores are enabled to reach a spot suitable for germination. And the parent sporophyte also furnishes the structures through which the pollen tube (male gametophyte) reaches the female gametophyte.

The fertilized egg remains within the wall of the gametophyte, but since this is within the ovule, it is nourished not by the "parent" but by the "grandparent"—the sporophyte. And the food which the seed accumulates is also supplied by the grandparent. The fertilized egg is nourished until the new

[1]See No. 6, p. 415.



ALTERNATION OF GENERATIONS IN PLANTS

Green moss plants are gametophytes, while ferns and seed plants are sporophytes. Seed plants surpass ferns and ferns surpass mosses in their ability to manufacture food, to protect the young, and to adapt themselves to a wide range of living conditions

sporophyte individual is pretty well advanced—in most species until the leaves, roots, and stem are definitely formed. And it is through the materials and activities of the grandparent that the seed is protected and finally sent off into the world on its own.

Parenthood in Seed Plants[1] Seed plants have come to be tremendously effective organisms as absorbers of material and of sun energy. Each individual expends a considerable part of this accumulated material and energy in ways that do not help it at all. The making of flowers and seeds, for example, do not contribute to the well-being or safety of the plant.

And advance in the scale of life seems to impose additional burdens upon the organisms. But these are more than compensated by the additional advantages. In a species that produces well-stored seeds, well-protected seeds, and seeds well adapted to wide dispersal *every individual gets the full benefit of this additional expenditure of energy at the very beginning of its career.* We might even say that a plant is able to do its life's work effectively just in proportion as it gets a good start. In doing things for posterity a plant is thus merely returning to the species what it received from its immediate ancestors.

Of course we are not to suppose that the plants do this or that *because* they have any feeling of gratitude, or ability to foresee future needs. In speaking of the advantages or disadvantages of various types of behavior on the part of plants, we merely note that certain kinds of doings may actually contribute to the prosperity of the species, whereas other kinds of doings might lead to the extinction of the species. Some plants behaved in a certain way in past ages, and their progeny today occupy the surface of the earth. Other plants behaved quite otherwise, and we know of them only by the traces they have left in the ancient rocks of the hills.

In Brief

The essential organs in all flowers, pistils, and stamens are those that have to do with producing seeds.

The pistil, or female organ, consists of a stigma, a style, and an ovary, which bears the ovules.

The stamens produce pollen, spores that give rise to male gametophytes, within the anthers.

Within the ovule a single large cell, the embryo sac, gives rise to the female gametophyte, the egg-producing organ.

The egg nucleus, generated within the embryo sac, and the sperm nuclei, generated within the pollen grains, each have but half the number of chromosomes found in the parent tissue cells.

[1]See No. 7, p. 415.

The sperm nuclei are carried to the egg nucleus within the pollen tube of the male gametophyte as it grows into the pistil.

Fertilization occurs when the two sexual nuclei combine.

After fertilization the mass of the embryo sac absorbs food and grows into an embryo; the surrounding walls of the ovule become the seed coats.

Fertilization also brings about the ripening of the ovary into a fruit; in some plants the calyx and even the receptacle become fused into the fleshy fruit.

In some species the flowers are usually or always self-pollenated; in others they are cross-pollenated.

Many flowering plants depend upon external agencies, such as wind or flying insects, to bring about pollenation.

The coloration, specialized structures and odors of flowers may be considered as secondary sex characteristics, since they are but remotely connected with the formation of the gametes.

Thousands of species would not survive the winter but for the hard, inert seeds through which they renew themselves when conditions again make growth possible.

Seeds are scattered in a variety of ways.

The offspring of flowering plants have the advantages of a good food supply and a wide dispersal in the well-protected seeds produced by the parent.

EXPLORATIONS AND PROJECTS

1 To find out how reproduction takes place in flowers, examine some complete, regular, perfect flower, such as a wild rose, sedum, tulip, evening primrose, geranium, forsythia, apple, lily, or gladiolus. Identify the stamens and the pistil, and compare these with stamens and pistils of other species. Open the ovary to locate the ovules; note their attachments and their arrangement in the one or several carpels. Identify the outer accessory parts, sepals and petals, the parts respectively of the calyx and the corolla. Identify the various structures in as many different species as time permits.

2 To find out how pollen carries the sperm to the ovule, germinate pollen grains and examine under the microscope.[1] Note the tubes projecting from some of the grains. Look for distinguishable structures—the sperm nuclei—within the protoplasm. Apply a little iodine or other stain to the side of the cover slip, to make the sperm nuclei more easily visible. Make longitudinal sections of some pistils to locate pollen tubes within. Relate the growth of the pollen tube to bringing the sperm from the stigma to the ovule within the ovary.

[1]To germinate pollen grains, rub them from stamens into a drop of a 3 per cent sugar solution on a microscope slide. Cover with a cover glass and set aside at room temperature in a moist chamber or germinating dish for twenty-four hours.

3 To find out what development takes place in the early formation of a seed, compare the ovaries of some pea blossoms, some partially developed pods, and some mature pods of peas. Identify the ovules in the ovary of the blossom; compare them with the ovules in a later stage and with the ripe seeds. Find evidences that not all the ovules in the pea pods were fertilized. Describe the development that takes place after fertilization.

4 To discover structures that favor or hinder self-pollenation or that favor cross-pollenation by wind or by insects, examine as many different varieties of flowers as are to be had and note:

a. Position of stamens with relation to floral envelope (whether exposed to the wind or shielded; whether corolla permits the pollen to be dusted off on any casual contacts, or is arranged so as to permit insects to enter only along special paths).

b. Position of the anthers in relation to the stigma (whether above or on a lower level, whether on same or on separate flowers).

c. Relative time of ripening of stigma and pollen (whether at the same time on a given flower, or whether at different times on the same flower).

d. The character and amount of pollen produced.

e. Shape and position of pistil with reference to contact with visiting insects or with wind-blown pollen.

f. Presence or absence of distinct colors, odor or sweet nectar.

List the structures that favor self-pollenation; those that hinder it; those that favor insect pollenation; those that favor wind pollenation. List the flowers showing each of these adaptive structures.

5 To discover how seeds travel, collect as many kinds of seeds as are available in an open meadow or vacant lot in the fall of the year. Note the various structures that relate seeds to moving air, animals, or other agencies. Look for seeds or fruits with hooks or spines; with a pappus, a hairy parachutelike arrangement; with wings. Look for fruits or pods which, as they ripen and dry, mechanically throw the seeds; for fruits encased in fleshy pulp. Note any other ways in which seeds travel. Classify the various kinds of seeds according to the manner or agency of dispersal.

6 To find the relation of the parts of the seed to the parts of the young plant, soak seeds of several varieties overnight (use Lima beans, peas, and corn grains). Remove coat from soaked seeds and carefully lay apart structures found. Make drawings to show structures and their attachments to one another. Identify the following: the hilum, the scar of attachment of the seed inside the fruit; the micropyle, the tiny hole through which the pollen-tube passed into the ovule; the embryo, or young plant, usually the entire contents of the seed coat; the cotyledons, or seed leaves, the large fleshy structures in such seeds as beans, peas, etc.; the hypocotyl, the little "tail" to which both cotyledons are attached; and the epicotyl, or plumule, usually lying between the cotyledons and attached to both. Compare the parts of embryo in different species.

7 To see how varying amounts of nutrition affect the growth of seedlings, place a quantity of soaked bean seeds and corn grains in a germinating dish, between layers of wet blotting paper; cover and set in a warm place. When the seeds

have germinated, remove from several of the corn seedlings varying fractions of the endosperm, up to half or more, leaving some uncut; and remove from several of the bean seedlings varying fractions of the cotyledon, up to half or more, leaving some undisturbed. Return to the germinating dish; cover and leave for several days longer. Compare the amount of growth in the various seedlings, with relation to the amount of endosperm or cotyledon removed. Tabulate the results and note conclusions.

QUESTIONS

1 What are the essential organs of a flower?

2 How do the sperm nuclei within the pollen get from the stigma to the ovule?

3 In what different ways is pollen transferred from the anthers to the stigma in flowering plants?

4 What are the advantages of self-pollenation? of cross-pollenation? What structures in different plants favor self-pollenation? favor cross-pollenation?

5 In what respects is reproduction in flowering plants more advanced than that in ferns?

6 How do spores differ from seeds? In what ways are they alike?

7 In what ways are seeds and fertilized eggs alike? different?

8 What are the advantages to a species of producing a relatively large number of eggs or seeds? the disadvantages?

9 To what risks or dangers are eggs and the young of plants or animals exposed?

10 In what sense can plants be said to care for their young?

1 Why is a cat more helpless at birth than a calf?
2 How does an animal benefit by looking after its young?
3 Why do not all animals take care of their young?
4 Against what do the young of plants and animals have to be protected?
5 Why do some species produce such tremendous numbers of eggs or seeds?
6 Can anything be done to hasten or to slow up the development of a plant or an animal?
7 Can a kitten's development be hurried by forcing its eyes open?
8 What makes a hen want to sit on the eggs at one time, but not at another?

Each plant and each animal typically starts life as a single cell. When a one-celled plant or animal reproduces itself, it gives up absolutely everything—its own individual existence—to the offspring. Young and old are much alike; the new individual at once starts out on its own.

In more complex organisms the initial cell is usually a spore or a zygote; and the initial stage is in every way different from the adult. Among the many-celled species the individual that reproduces normally holds on to life, but the new individual is helpless and dependent.

In what ways are the more complex species better off than the simpler ones? Why do we call them higher? In what ways are the simplest organisms less capable of surviving?

Why Do We Consider Some Forms of Life Higher than Others?

Lines of Differentiation Even among the lower classes of many-celled plants and animals, specialization of function is already beginning. And there is a corresponding specialization of structures or of organs. In the hydra, for example, the outer and the inner cell layers behave differently in relation to external stimuli and in relation to food; the middle layer gives rise to reproductive cells (see illustration, p. 274). The cells grow and divide, as in one-celled animals, according to the food supply and other conditions. But the whole individual continues over a much longer period. The longer span of life means more development, more ways of getting about, more ways of getting food—and more dangers to run into, too.

The earliest division of labor in the history of life is probably that between food-getting and food-using, as in the hydra. We might even go farther back and think of the entire plant world and the entire animal world as distinct

lines of differentiation. One line departs from a more primitive life by specializing in vegetative activities; the other specializes in using up food (see frontispiece.)

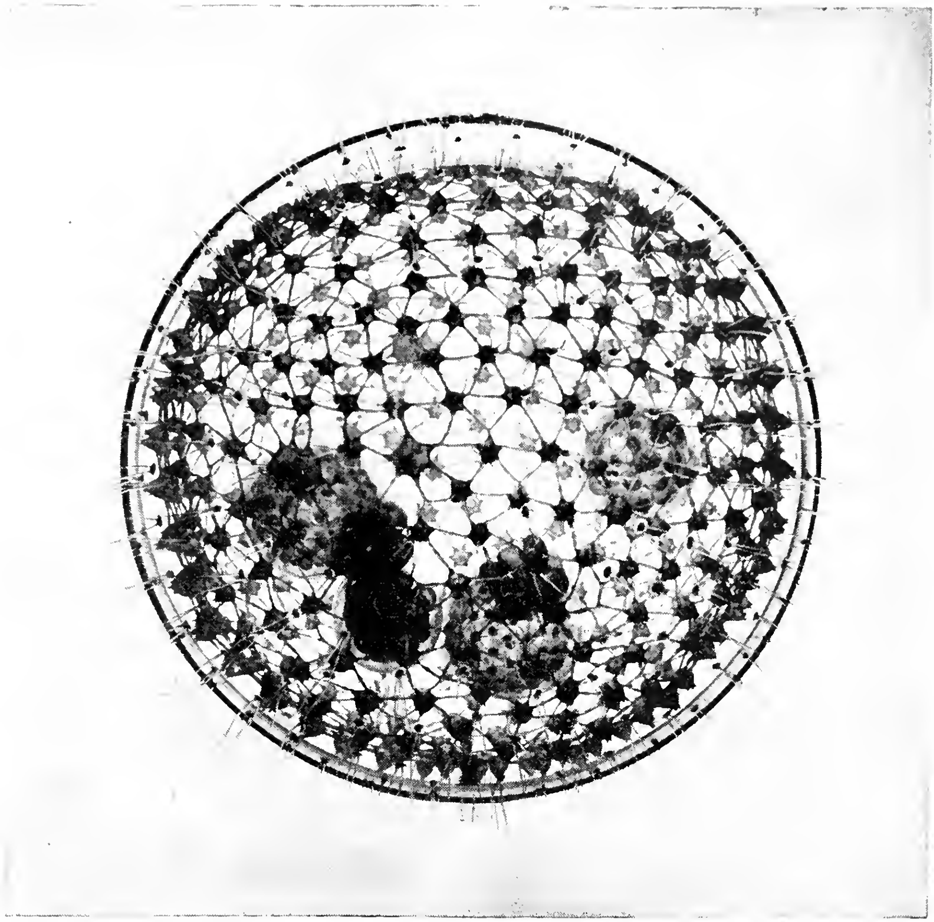
Complex systems of organs make possible a greater variety of life outside the water. We have seen how ferns and seed plants managed to free themselves from dependence upon constant wetness (see page 386). Each land animal in effect carries about in its body a section of the primitive ocean, so that it is able to tolerate a great deal of variation in external moisture. Birds and mammals maintain a fairly uniform temperature and a fairly uniform rate of metabolism on the inside, in spite of the great changes in outside temperature. In these respects the "higher" animals are free from the constant changes in temperature and moisture, which constantly suspend or stop metabolism in simpler organisms.

Food-getting, protecting, body-building, and other processes are apparently carried on more efficiently in organisms having specialized organs and tissues. It is true that in the common plants and animals a considerable part of the body consists of nonliving materials, such as wood and bark or bone and shell. Nevertheless such an organism can grow a much greater total of living matter from a single cell in a season, or in the course of years, than can a simple organism that is nearly all protoplasm—like an ameba, for example.

"Division of labor", or specialization of functions, operates in an organism about as it does in human society. Through becoming specialized, each unit carries out its particular processes more efficiently, although it neglects others. It can produce a surplus of its specialized product or services. It can continue to live, however, only in co-operation with other specialized units. The exchanges and co-ordinations of the many different organs use up materials and energies. This is like the fact that modern industrial and commercial life uses up more work and materials than older ways in hundreds of tasks that are not directly "productive"—transporting, communicating, recording, accounting, managing, and so on. But these additional needs are more than made up for by the increased effectiveness of the total.

Thus a blood system consists only in part of living protoplasm; a bone system carries on very little "growth" after it has reached full size. Yet the blood makes possible a much higher degree of effective brain and muscle and gland work in all parts of the body than the various cells could carry on as independent units. The bones make possible the building up of masses of protoplasm that could not otherwise hold together. The greater the degree of specialization, the greater the amount and also the intensity of living.

Vegetative and Reproductive A one-celled organism absorbs and assimilates food, and grows: that is *vegetation.* Past a certain point the cell does not grow further, but divides into two cells. While we might call this act



American Museum of Natural History

SPECIALIZATION IN VOLVOX

The cells arranged in a single layer as a hollow sphere are connected with one another by strands of protoplasm. Each cell, with its chlorophyl and vibrating cilia, carries on all the life functions except reproduction. Certain cells within the hollow sphere become segregated: these specialize in reproducing new colonies

reproduction, exactly the same process in a many-celled plant or animal results merely in growing larger, becoming more. When a many-celled organism produces spores or gametes that we can distinguish from the parent, we can distinguish reproduction from vegetation. Certain cells now arise that cannot continue to grow and divide except as an individual distinct from the parent tissues. Reproduction has become differentiated from vegetation.

This differentiation of reproduction from vegetation, or of offspring from parent, means that *reproduction* can become more than *replacement*. The life of the parent organism, past the point of reproduction, is in a sense a net gain.

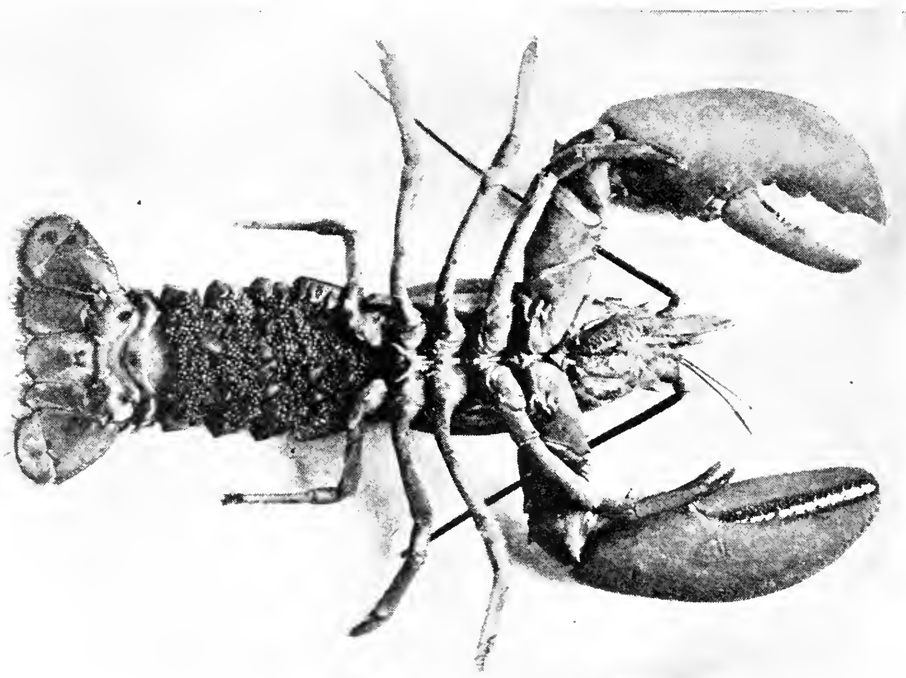
It means that more life is going on than merely keeping alive and being replaced. As in differentiation of structures and functions in vegetative life, the specialization seems to yield more than it costs.

In What Ways Do Animals Care for Their Young?

Infancy among Animals[1] Among most of the lower animals the mother lays large numbers of eggs—in the water, on leaves, in the soil—and abandons them. But toward the upper end of many series of animals we find that the parents supply much more for the young. The lobster and crayfish mothers carry the eggs about on their abdominal legs, or swimmerets, and they carry even the young embryos until they are able to care for themselves (see illustration below). Among the insects some species abandon their eggs as soon as they are laid, whereas others supply shelter and food for the young.

In some species of toads the father places the fertilized eggs in his mouth and keeps them in his croaking pouches until the tadpoles are large enough to swim away. Several species of newts and salamanders guard the developing young within the body of the mother until the young are fully formed and able to shift for themselves.

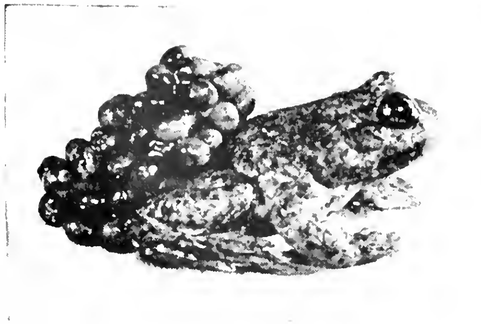
[1]See Nos. 1 and 2, p. 432.



United States Fish and Wildlife Service

A "BERRIED" LOBSTER

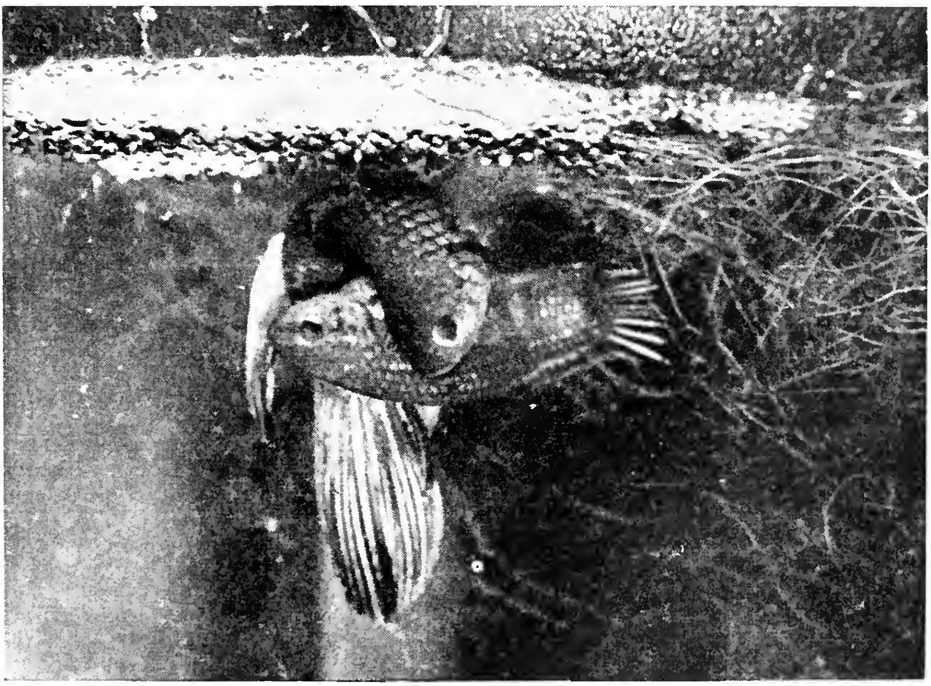
In some species of toads the fertilized eggs are carried about on the back of the female until the tadpoles are able to swim away. In other species the male tangles the gelatinous string of fertilized eggs around his body and hind legs and carries the offspring about until the tadpoles swim away. The male of still other species of toads carries the hatching eggs about in his mouth



American Museum of Natural History

MOTHERING AMONG TOADS

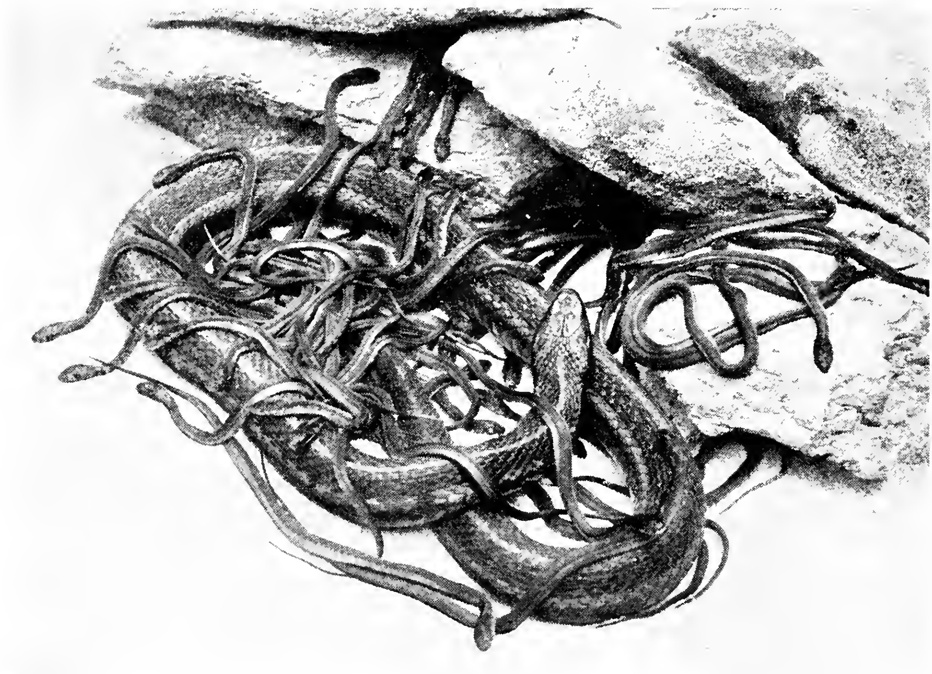
Among the reptiles and birds the fertilized egg begins to develop inside the parent's body; and before the young embryo is removed, it is surrounded by a mass of food material (the yolk and the white) and a protective shell.



New York Zoological Society

BREEDING HABITS OF SIAMESE FIGHTING FISH

After building a bubble nest for the eggs, the male Siamese fish twists his body around the body of the female, fertilizing the eggs as she discharges them. As the eggs drop, both the male and the female take them in their mouths and place them in the nest. The male then drives the female from the nest and guards the eggs until they hatch



New York Zoological Society

A VIVIPAROUS SNAKE

In the garter snake and in some other species, the fertilized eggs remain within the body of the mother until the young are developed to the adult form

Most reptiles and some birds leave the eggs, which are hatched by the heat of the sun or at ordinary temperatures. Most of the common birds, however, build more or less elaborate nests and keep the eggs warm during hatching. And most birds care for the fledglings, as well as the eggs. In many species the young learn their "song" from the parents or other older birds. Domesticated canaries are sometimes trained as songbirds, or at least protected against undesirable noises, since they are very imitative. The feeding of young birds by the parents is a very interesting operation to watch, as it shows the development of rather complex instincts.

Infancy among Mammals We consider the mammals the highest class of vertebrates—and indeed of all living things. In this class the dependence of the young upon their parents is carried to the greatest extreme. In the entire class the female develops special milk glands—hence the name, from *mammae*, the breasts or teats. Related to the presence of the milk gland is the infant's equipment of nerve-and-muscle sucking mechanism, and his complete dependence upon the milk supply for his nourishment.

In the marsupials the egg hatches within the uterus of the mother, as in the "true mammals", but the fetus leaves at a rather early stage — in the

Growing Period of Various Mammals

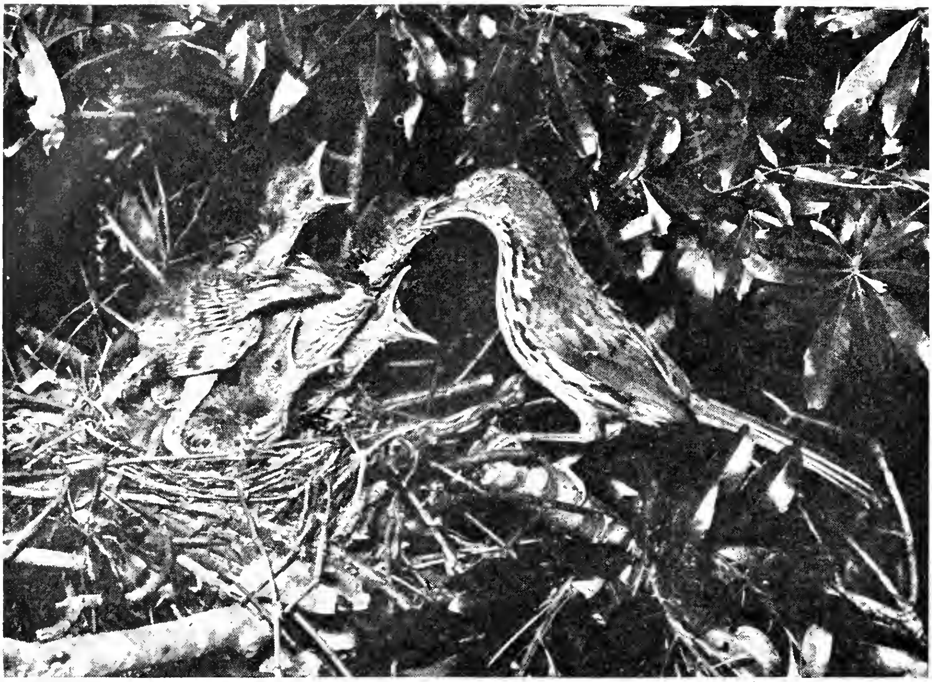
ANIMAL	GESTATION PERIOD	MATURING TIME	LIFE SPAN
Mouse	20–30 days	6–7 weeks	6 years
Rat	21 days	8–9 weeks	3 years
Rabbit	30–32 days	6–9 months	8 years
Guinea pig	9 weeks	7 months	7 years
Cat	8–9 weeks	1–2 years	12–23 years
Lion	16 weeks	6 years	30–40 years
Dog	9 weeks	10 months–2 years	15–30 years
Fox	60–62 days	18 months	13–14 years
Sheep	21–22 weeks	1–$1\frac{1}{2}$ years	12–15 years
Pig	4 months	5 years	30 years
Cattle	9 months	2 years	30 years
Hippopotamus	8 months	5 years	30 years
Deer	10 months	$4\frac{1}{2}$ years	40 years
Camel	13 months	8 years	40 years
Horse	11 months	2–4 years	30–60 years
Elephant	20 months	30–35 years	100 years
Monkey (*Macacus*)	6 months	2 years	18 years
Man	270–280 days	20–25 years	75 years +

largest species, the kangaroos, when only about two inches long. The mother places the newborn young in the brood-pouch, where they are kept protected and warm and where they feed on milk from the glands of the mother.

As we go from the lower orders of mammals to the primates, we find that the young are protected and nourished for a longer period *preceding* birth. And the young depend upon their parents for longer and longer periods *after* birth also. The table above compares several species of mammals, including man, in regard to the period of gestation within the mother, the time to sexual maturity, and the total length of life.

The Embryo in Mammals Among all except the pouched and the egg-laying mammals (see Appendix A), the embryo remains within the uterus of the mother until it attains a body form resembling in a general way that of the adults of the species. While still a tiny spherical mass, suggesting a golfball with a fluid interior, the fetus attaches itself to the lining of the uterus (see illustration, p. 383). Outgrowths from the surface cells dig into the lining by a sort of digestive process, with the result that the fetus comes to be surrounded by lymph from the mother's capillaries. Nourished through the extensions into the tissues of the uterus, the inner cells of the fetus grow and divide rapidly, and the mass takes on a definite form — which is steadily changing (see pages 354–356).

The outer layer, with its extensions, also enlarges and acts as a special nutritional organ until the embryo completes its development. This special organ is called the *placenta* and has multitudes of villi, or outgrowths, which contain blood vessels. These villi are somewhat like the villi of the



S. A. Grimes, from National Audubon Society

MOTHER BROWN THRASHER FEEDING HER FAMILY

Among most species of birds the new individual depends upon the parents for the heat that is essential for the development of the embryo; and the newly hatched birds depend entirely upon the parents for food and protection during the first few weeks

intestines (see page 171); but whereas the villi of the digestive system extend freely into the food cavity, those of the placenta are embedded among blood vessels of the uterus. The blood stream of the embryo is supplied with nourishment from the blood stream of the parent, but the two streams never mingle: they are separated by the two distinct sets of capillaries and by lymph spaces.

The embryo is thus in every sense a "parasite", living within the larger organism. Diffusion is constantly taking place between the blood vessels of the uterus and the blood vessels of the placenta, which are parts of the embryo's circulatory system. In this diffusion there is an exchange of dissolved food and of dissolved urea and other waste substances resulting from the metabolism of the embryo. There is also an exchange of dissolved oxygen and carbon dioxide. The embryo thus depends upon the mother not alone for its digested food supply, but for its respiration and excretion too — as well as for mechanical protection and a constant temperature.

The capillaries of the placenta are connected with the blood system of the embryo by way of arteries and veins running through a flexible "umbilical

cord". At birth the placenta detaches itself from the lining of the uterus, and then the umbilical cord is torn and broken off close to the infant's abdomen, leaving the familiar scar, or navel.

Behavior of Parents Among the mammals, and to a less degree among the birds, the long dependence of the young upon their parents is associated with corresponding behavior of parents and offspring. The hen clucks a danger signal and the chicks rush to cover under her wings: she enfolds them and threatens to fight anybody who comes near. The cow licks her calf with her tongue, and the calf seems to like it. If you try to take the eggs from an eagle's nest, or to touch the young, you run the risk of a dangerous attack by the adults. The ferocity of the mothers of the cat family is notorious. And with most species of birds and mammals, the young behave in relation to the adults in a manner that impresses us with its fitness, its adaptability to the needs of the organisms or of the species.

On the whole, the most dependent of infants do normally get off on their own at last; and then they seem to have a fuller equipment of life tricks and reserves than those which get on their feet more promptly after birth. There are great variations as to the length of time that the offspring depend upon

MOTHER LOOKING AFTER HER YOUNG[1]

The raccoon feeds and protects her young ones until they are about a year old

[1] From *Look at Life*, by Lynwood Chace. By permission of Alfred A. Knopf, Inc.

European

KOALA BEAR TOTING HER YOUNG

At eight months of age this young marsupial is no longer carried in the pouch on the mother's abdomen, and it is able to eat a little of everything that the adults eat. But the mother still carries the baby around and protects it

the parents among different peoples, and even among different sections of the same population, as the rural and urban in America.

Infancy in Man[1] The length of immaturity and dependency differs among various races of mankind, and among different types of culture. Children among primitive people run about with little direction or supervision almost as soon as they can walk. In a modern industrial community they are

[1]See No. 3, p. 432.

sometimes closely watched even at their play, until they are well on in years. These differences in customs are to a degree conventional and more or less arbitrary. Some of the differences are probably adaptations to extreme conditions of climate, for example, or of crowding. Or they may be related to natural resources, for when food is abundant young and old are likely to be carefree and easygoing. It is possible, too, that among races, as among varieties in some other species of animals, there are inherited or constitutional differences, as well as those connected with the modes of living.

One of the important differences between human beings and other animals is the ease with which humans learn, or change their "instincts". Living for a long time in one place or with other people produces an effect. One becomes "attached", as we say; one's feelings become involved. And this applies to parents and young both. We learn to like, we learn to love deeply—just as we learn to dislike unpleasant associations, things and places and people that hurt or annoy us. Children imitate their elders and they learn many tricks about getting along, about what to eat and what to avoid. They learn how to do various things, how to manage various situations.

By the time they are running about and getting acquainted with other children, our youngsters already have a substantial amount of lore to guide them, to protect them. If the shelter of older people continues, they may presumably accumulate more skills, more useful knowledge, more understanding of how to deal with various problems and situations. It is for these reasons that so much effort has been made to increase and to improve schooling. The idea has always been to give young people the greatest possible amount of preparation before they are exposed to the difficulties and dangers of adult life. And, generally speaking, communities or cultures that have made the greatest provision for their young have also managed to get fuller and longer lives for their members.

Are All Plant and Animal Activities Necessary for Living?

Necessities and Extras We depend for our subsistence upon plants and animals, and eventually upon photosynthesis and nutritive processes. We are, of course, interested also in the reproduction of plants and animals, and for two distinct reasons. We want an abundance of the useful plants and animals, and that means regulating their reproduction. And we also depend more and more upon grains, fruits, and seeds of plants, rather than on leaves, roots, and tubers; and we are using greater quantities of eggs and dairy products, as against the flesh of animals. But people seem to be more fascinated by some of the "secondary" structures and activities associated with reproduction and with the preservation of the various species. One does not need to be a scientist or a practical farmer or a technician to be interested in flowers or in the songs and plumage of birds or in the playing of a cat with her kittens.

Is there among other species a similar interest in experiences or activities that are not essential to life? We do not know how the secondary sexual characters originated, nor how important they are in maintaining life. But human beings cannot avoid speculating and wondering and experimenting. And perhaps we cannot help trying to use the ideas we get to support our older beliefs or preferences. For example, many secondary characters are clearly related to sexual reproduction in species that live far from the original home of life in the ocean. But it does not follow that all secondary differences between males and females contribute to this result or are otherwise useful to the species. We know that in many species of moths the two sexes have different wing patterns and colorings, which have nothing to do with mating. These insects fly and mate only at night, anyhow, and their movements are apparently directed by odor. One experimenter glued wings of males on female bodies and vice versa, and discovered that the male finds the female just as well.

It is easy for us to "explain" what other living things do as if plants and animals had feelings and tastes and purposes and enjoyments like our own. Indeed, we sometimes give them credit for being more able and more clever than we are ourselves. Perhaps the honeysuckle grew itself flowers in order to attract insects so as to get them to carry pollen and so help it produce seeds. Perhaps the male elk grew himself large horns in order to impress the female of the species or in order to overcome rival males. Perhaps the nightingale grew himself a song box, and the goat grew himself whiskers, in order to attract the female. Perhaps. But would any of us claim that we grew ourselves our own attractive or effective colorings, our hands and teeth and other features, in order to . . . ? We really don't know.

Life is possible without the secondary sexual characters, as it is, indeed, possible without sexual reproduction. Fine feathers and showy flowers are of themselves without apparent "uses" in the economy of the individual organism. They consume energy and material, and they seem to contribute nothing toward keeping the individual alive.

In the course of time, however, modes of life seem to have become more complex and to have involved more complex modes of reproduction. All the elaborations in plants and animals, whether related to vegetation or to reproduction, seem to have arisen only when there was a surplus of food and energy. When a few algal or protozoan cells cling together after cell-division, instead of drifting apart, there is already the possibility of some surplus. Where several cells have teamed up, they can increase their total product through division of labor; and their joint action makes it possible to produce "extras" —which may or may not become "useful".

We know that in the long run tools and machinery more than pay for themselves in human organization. But we cannot design, not to say con-

struct, such devices until we have on hand a reserve of food, housing, clothing, materials, and other *necessities* upon which people can live while they are producing these extras. In the same way, the extra and often extravagant developments in plants and animals become possible only where the race or species is already able to maintain itself and still produce surpluses for "ornament" or "display".

In its exuberance, life sometimes runs off into extravagant, bizarre, and even wasteful forms. But that is no more astonishing or mysterious than the more precise and economical adjustments of structures and functions about which mankind has always marveled. And the uses to which exuberant human beings put their surpluses of time and energy and materials are often quite as extravagant or bizarre.

The Human Side From a human point of view, life is, of course, possible without song or fairy-tales or play-acting or adventures or frills, just as it is possible without schools or motion pictures or airplanes. Among the most primitive of humans however, there is a disposition to ornament or decorate, to sing and to dance, and to tell fish stories. The amount of such "play" in the lives of people depends largely on how much free time and energy and materials are available after food and other necessities have been assured.

The distinctive things we remember about the past, or that we find interesting in strange peoples, are their art, music, dance, oratory, fiction, drama, poetry, architecture, decorations. The rise and fall of civilizations have been inseparable from the cultures of peoples, from the skill with which they have kept themselves well and supplied with the essentials, from the uses that they have made of their surpluses. In human life it is the play of fancy and the creation of beautiful accessories to life that matter—the dreams and religions and sciences and philosophies. And in particular individuals it is these things that really mean most to us.

These distinctly human expressions of life trace back to savagery. Savages were able to make slow accumulations of surpluses, as well as of past experience, by continuing to live together in groups or as families. We cannot say that primitive men and women decided to look after helpless infants, or to cling together after the mating season, because they saw some advantage in doing so. It is more reasonable to assume that the earliest associations of males and females or of parents and young were unconscious or "instinctive". They appear to be so with other species. Man is a social animal: human beings apparently preferred companionship to solitude before anybody thought about it.

The association of individuals of all ages in a co-operative group results in developing affections and mutual regard and consideration. However family or social life first started, we may reasonably suppose that it continued among human beings and expanded because it yields practical advantages and increasing satisfactions—because it adds to the life of persons. In his individual

development a person ordinarily acquires attachments to those close by, and as he grows up he attaches himself to *more* groups. And he comes normally to feel himself a member of an ever *larger* group. He depends upon others and comes to help others in ways that create more satisfaction for all than would be possible if each tried to live alone.

The Family and Civilization All the records we have of human living show that, whatever the form of society, people always lived in families. The individual is born into the family, he is shaped by the family, and he normally expresses himself as an independent adult through the family. All social life, then, rests upon the family, which first of all nurtures and protects the infant. The amount of care given to the child determines the degree of social development. And this is also an index of social development. That is, the more advanced a civilization is, the more it uses its resources for the benefit of children and youth. And the more effectively any civilization serves its children and youth, the better off is the entire community likely to be.

It is a sound principle for any civilization to protect and free its youth, but there is no simple rule for applying this principle. It is a mistake, for example, to assume that postponing the problems and responsibilities of life will itself ensure advantages for the protected individuals. Boys and girls who have all their needs supplied and who are as "free" as babies from any obligations are likely to grow up into rather helpless and useless persons whom nobody likes but themselves.

For over a hundred years in this country thoughtful people have recognized that protecting the health and development of children brings *general* benefits. Schooling and legal protection are of public concern, not merely privileges for those who can afford them. Training and educating children result in the well-being and happiness of the whole community. But it does not follow that every individual will gain from every additional year of schooling, or will be better off as an adult, or a better member of the family or the community, because of more schooling. For schooling, past a certain point, like food or medicine or clothing, has to be suited to the particular individual. And it has to be suited to the kind of culture in which he is to live.

To be effective and cumulative, the gains of civilization have to reach down to the infant long before the child can take part in schools or clinics or radio concerts. Most of our devices for better living act upon the individual through the family. Health services attempt to reach the child before he is born, through maternity clinics and through the education of parents. The nutrition of children before school age has come to be a matter of public concern, especially in time of war. Every child brings with him to school or kindergarten, out of his home, a multitude of conditionings and attitudes that influence the way he adjusts himself to social living. Some children

overcome the handicaps of homes that are lacking in material and cultural resources with great difficulty; and some never do.

A single measure of the social and the organic advantages of providing children with more care and services may be seen in varying birth rates. Among the vertebrates that do the least for their offspring, each female produces and distributes thousands, even hundreds of thousands, of eggs, and so contributes to keeping the species alive—that is, she so replaces the adults. Among the mammals and birds each female produces a few or only one or two young at a time, and so the species maintains itself.

Among human beings a mother bears from a very few to twenty or more in the course of her life. But in some types of social life it takes a dozen or more children per family to keep the population constant, whereas in other types an average of about three per family can maintain the population. Where the young are well cared for, adults find many interesting things to do besides bear many children—and bury most of them. Or, from another point of view, where there are only a few young, the adults can furnish them the best of care and preparation and still have more time for themselves to spend in useful and interesting ways; at the same time each developing individual can have more resources and better preparation for using the adult years in productive and satisfying ways.

In Brief

Accompanying the ascent of plant and animal life from the lowest to the highest forms, there is an increase in the dependence of the offspring upon the parent.

In more complex species the individual remains relatively longer dependent upon the previous generation, and is in turn better equipped in development, and often in reserves of food, to live in a more complex environment.

Among the mammals and to a less degree among the birds, the long dependence of the young upon their parents is associated with a corresponding behavior of parents and offspring.

In the higher forms of life the species generally maintain themselves with relatively fewer offspring.

In advancing civilizations, as in advancing forms of life, the extent to which each generation provides services and reserves for the offspring is related to the level of development.

All social life rests upon the family, which first of all nurtures and protects the infant.

To be effective and cumulative, the gains of civilization have to result in improved conditions for the young.

EXPLORATIONS AND PROJECTS

1 To discover to what extent guppies care for their young, raise some under observation. Compare the activities of the parents in relation to the young with the conditions that you would furnish to ensure survival of the young. Compare the parenthood of guppies with that of domestic animals with which you are familiar.

2 To study the behavior of birds in rearing and caring for their young, locate a pair of birds that are building their nest (in the spring). Watch activities of the birds from day to day; note when the first egg appears; note when the female starts sitting on the eggs; note what the male does. Record date when first egg hatches and, if possible without disturbing the family, take a picture of the young. Continue daily observations until the young have left the nest. Keep definite records, with pictures if possible, to show successive stages in the development of the young birds. Note factors in the behavior of the parents that seem related to (*a*) self-protection; (*b*) welfare of offspring; (*c*) other possible "values". Note factors in behavior of young that seem related to (*a*) their dependence, or helplessness; (*b*) their progressive adjustment, or independence.

3 To survey the variety of practices among human beings in relation to infancy, find out what is available regarding parent-child relationships among different peoples. Note what most primitive people do with or for their young. Contrast types of education, guidance, and regulation of children in a primitive tribe with corresponding services of our time. Compare the kinds of parental care given by various sections of our own population in guarding the health of their children; in helping their children prepare for their vocations or professions. Relate differences to probable causes.

QUESTIONS

1 In what different ways do animals care for their young?

2 What are the advantages to a species of having the offspring become self-sustaining at the earliest possible moment? the disadvantages?

3 In what respects is human infancy like that of other animals? In what ways different?

4 What are the advantages of the early parental care provided by birds and mammals? the disadvantages?

5 How is the duration of infancy in man related to the civilizations he has developed?

Everybody has known for centuries that chickens come from hen's eggs and that great oaks from little acorns grow. But not everybody knows that living things come only from other living things more or less like them. And until comparatively recent times, hardly anybody could be sure of this. For there are endless tales of maggots coming out of decaying meat, of horsehairs turning into worms, and of mud becoming converted into eels or frogs. Indeed, many sober-minded persons had reported seeing such things happen under their very eyes.

Still more difficult has it been to reach clear notions as to just what goes on in the egg to convert it into a chicken; or as to what happens to make the acorn be what it is, with its wonderful capacity to grow at all, or to grow into an oak and nothing else. It has seemed reasonable to ask, Is there a preformed miniature hen inside the egg? Or does formless matter become changed into the organized bird? But we have learned enough to see that the answer is neither one nor the other. There is indeed no miniature hen. But neither is the living part of the egg formless. It is a highly complex and highly specialized bit of matter that becomes a particular hen, of a particular breed, through an orderly series of changes. And every individual plant and animal passes through an orderly series of changes in much the same way. The transformation of a microscopic germ into an individual involves growth—increase in the amount of protoplasm. And it involves development, a process of becoming progressively different.

We accept the familiar fact that wounds and bruises heal. But we are impressed when we see missing organs replaced, even to the extent of making "new individuals" out of fragments of old individuals. These various kinds of happenings, however, are essentially of the same order. We may think of regeneration of common plants and of a few animals as a special aspect of growth: new cells are formed by cell-division. Vegetative propagation or reproduction is an extension of the fact of *growth* and repair of tissue. More highly specialized is the formation, among most common plants and some animals, of buds or outgrowths which can develop into independent individuals.

In general, the making of new individuals is closely related to the fact that no living beings can continue to live forever. We may think of reproduction as the continuing of life processes from individual to individual or from generation to generation. Plants and animals almost universally produce special structures or stages that keep "alive" under conditions that do not permit normal metabolism. Spores, seeds, pupae, cysts, protected eggs, survive drought or cold or heat in what is essentially suspended, or extremely reduced, metabolism. Whatever goes on inside such structures is more or less

independent of external conditions. They are, so to say, means for bridging a special interval of time. And sometimes they also span space, as in the case of migratory spores or the seeds of many species.

As we survey life forms from the smallest and simplest to the familiar and complex animals most like ourselves, we see a progressive increase in the amount of differentiation that takes place during the individual's development. That is, there come to be more kinds of cells, more kinds of organs and tissues. This differentiation includes the appearance of specialized reproductive structures and processes. These culminate in sexual, as distinguished from vegetative or asexual, reproduction. In this process, among plants as among animals, two germ cells or units of protoplasm unite into one, which becomes the beginning of a new individual.

In the simplest forms of sexual reproduction, almost any cell may act as a gamete. But there is a progressive differentiation of gametes into *male* and *female*. The two gametes differ in the simplest forms chiefly in size. But in later forms they show other distinctive characters, such as relative motility and relative amount of accumulated food material. There appear highly specialized gamete-bearing structures, with various adaptations to the distribution of gametes and to the bringing together of sperm cells and egg cells.

Along with specialization of gametes there is a progressive development of secondary sexual characters. These involve, among the more complex members of the various plant and animal phyla, modes of behavior that distinguish the male and the female of the species. And there is further development of specialized structures and modes of behavior that have to do with the protection of zygotes and their distribution.

In the higher vertebrates, organs and processes related to perpetuating the species develop side by side with organs and processes that increasingly free the organisms from external conditions and dangers. And from a human point of view, there is a tremendous increase of free activity that brings satisfactions over and above merely keeping alive. There is in particular the exceptionally long period of childhood, in which relative freedom and security make it possible to develop talents and interests of great personal and community significance.

UNIT SIX

How Did Life Begin?

1. How did life begin?
2. Did all kinds of living things begin at the same time?
3. Is there life anywhere else in the universe besides on our earth?
4. How can we tell about the kinds of life that there were in very early times?
5. Has the earth always been populated with the same kinds of plants and animals?
6. Can living things come into being today from non-living materials?
7. Why are there not the same kinds of plants and animals in different parts of the world that have the same climate?
8. What kinds of characteristics are inherited? What kinds are not?
9. How can we tell that distinct kinds of plants or of animals are related?
10. How do we create new kinds of plants or animals?

From what we know it is reasonable to believe that all things living today are the direct descendants of similar plants and animals—that they came from parents. And we may assume that these ancestors also came from parents, and so on back for generations and for centuries. But this process of living and reproducing similar offspring could not have been going on forever. For there is good reason to believe that at some time in the past the conditions on the surface of the earth were not suitable for any of the existing plants and animals. There must, then, have been a time when there were no plants or animals at all. What were the ancestors of present-day species? How did life start in the first place?

We expect different species of plants and animals to inhabit different climates. But the tropical animals of Africa are different from the tropical animals of America. And the inhabitants of the southern Temperate Zones are different from those of the northern Temperate Zones. Did the ancestors of these different groups come into existence separately? That may well have been, for all we can tell. We are puzzled still further by another fact: although these widely distributed species are different, they have in common very much that is apparently unrelated to their conditions and modes of living; and yet they seem to develop along the same basic pattern.

We assume from our daily observations that every living thing reproduces its own kind—that figs come from fig trees and kittens from cats. Human children generally resemble their parents more than other members of the species. Brothers and sisters resemble each other more than they do their cousins. But then, even the offspring of the same parents are not *exactly*

alike. In fact, we can find differences even between twins. Does this variation continue, for any species, in any particular direction? Is there steady improvement or steady deterioration? Does any species, in the course of time, show more and more or less and less of any particular trait? If the actual forms of life come to differ as time goes on, the process must be very slow. For we do not observe such changes in a lifetime, nor have we any records of several thousand years of human history to answer these questions with assurance.

Certain evidences, however, leave no doubt that there formerly existed species which no longer exist: these are the fossils. And there is reason to believe that at various periods in the past the plant and animal species of today did not exist at all. What is the connection between the species of the present and the utterly different species of the past? Or did each species come into being independently of the others?

We cannot help wondering, for example, how life came into being or how it came to be what it is. More practical questions concern the sources of human qualities, the possible relation between an individual's characteristics and the characteristics and conduct of his parents. How can we preserve useful plants and animals against deterioration? How can we improve the qualities of domestic plants and animals?

Where did mankind come from? In what way is man related to the rest of life? What is man's destiny? How can we get dependable answers to these questions? What practical difference would the answers to such questions make?

1 If all life comes from life, where did the first come from?
2 Was there only one form of life at the beginning, or were there many different species?
3 Did life start in all parts of the world or in one region and then migrate to other places?
4 If life could start by itself at one time, why can it not start at another time, or in various places?
5 If life had a beginning, then is it not likely to come to an end?
6 If life originated from nonliving matter, would it not be possible to create life artificially?
7 Has life originated on other planets or in other parts of the universe?
8 Are there any things that stand between living and not-living?
9 Could life have come to the earth from some other planet?

Every primitive people has its own explanation of the source of life and of the nature of life. The god on the sun brought life down to the earth. The daughter of the ocean came up with life. A great bird came from over the sea, with the eggs and seeds of all the different species. It was the sunlight acting on the mud. It was an invisible spirit, "a breath", that entered the clay and made it live.

The notion of "breathing life" into lifeless matter is very old. Man's early conflicts with other living things—larger animals, lions or bears—impressed him with the greater amount of "life" which they had. Heavy breathing is the very sign of a powerful and dangerous enemy. The last breath of a dying person is often a heavy expiration. And when the breath goes, life ends.

The creation myths of primitive peoples were all very much alike, except for the names of the gods and the symbols employed. How do they differ from our modern answers? In what way are modern answers better? How, indeed, can we know what happened so far in the past?

How Can We Know about Life in the Past?

Before We Were Born[1] What happened before our time or outside our experience we have to learn from others, usually. If we trust those who tell us, we believe. If strangers or people we dislike tell us, we generally do not believe. As we grow older, however, we may find that our authorities often know only what others told them. Or that, like ourselves and other human

[1]See No. 1, p. 449

beings, they are sometimes mistaken. Then we want evidence that is more reliable than goodwill or sincerity. What kind of evidence do we want? What kind is possible?

We can know about the past, and especially about events that occurred before *any* human being could report or record them, only by interpreting significant facts. But the only facts we have are about *present* conditions in the world and about processes *now* going on. What can present facts tell us about the past?

The facts themselves tell us nothing. They take on meaning only as we ourselves make up our minds as to how things come to happen. If we make certain assumptions about the workings of the world, the facts tell us one thing; if we make other assumptions, the same facts tell us something quite different. We know, for example, that the farther we dig into the earth, the hotter it gets. One person concludes that when the earth was made, the core was made hot and the crust cold. Another, from the same "facts", declares that something is happening inside the earth to generate heat. A third might say, "The earth must have been very hot at one time, and it hasn't completely cooled yet". Or take the fact that brooks and rivers wear away soil and rocks, which later settle to the bottoms of lakes and ponds and oceans; or the fact that rocks are found in layers of different thicknesses, and at various angles. One person says, "When the earth was made, parts of it were laid in horizontal layers and other parts were made with layers slanting at various angles". Another person might say, "In the course of time sediment became hardened into rock; some layers took much longer to form than others; the character of the sediment varied from time to time; something must have pushed the horizontal layers out of place".

Choice of Assumptions We all make assumptions about the nature of the world, about why things happen as they do. But we do not all make the same assumptions. In these imagined cases one observer seems to assume that "the world was made" once and for all and has remained as it is from the beginning. Another seems to assume that what we see today is the present state in a long *process*, that what *is* has come naturally out of what *was*. We are apparently free to assume, or "believe", whatever we wish. But the choice we make is not entirely a matter of taste or of religion. For our assumptions turn out to be of great practical importance.

In all practical studies—agriculture and engineering, medicine and statesmanship, business and housekeeping—three sets of problems have to be solved: (1) *How can we cause desirable changes to take place?* (2) *How can we prevent undesirable changes from taking place?* (3) *How can we best meet unavoidable changes?*

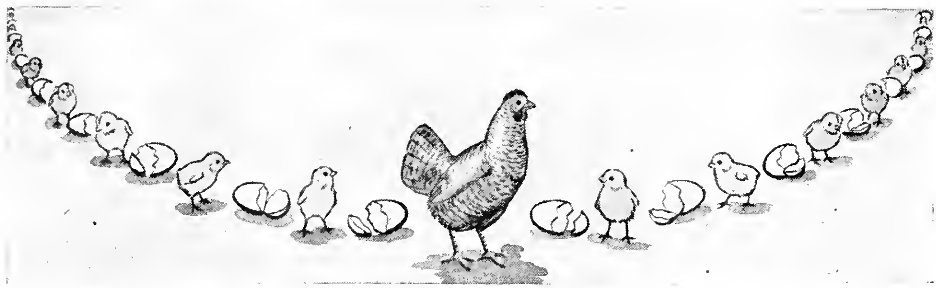
To solve such problems, however, we must first settle the "theoretical" question *How do things work?* What are we to assume about the world? We

can shrug our shoulders and say, "Anything might happen; there is no way of knowing". But it appears to be more profitable in every way to assume that all happenings are related, that there is a connection between what happens today and what happened yesterday, that the materials and forces operate consistently and not erratically. We do better by depending upon the consistencies which we can observe—that is, upon experience. That helps us to interpret the past, as well as to plan the future.

Everybody does probably assume that there is an order and consistency in the happenings of the world. If one really believed that "anything can happen" without regard to what had happened before, he would be living in a world that had no certainties in it whatever, in which you could not be sure that food would ever reach your mouth or that it would do inside you today what it did yesterday. The difficulty comes when we ask questions about things that are not familiar; and when thinking becomes difficult, some of us give up. At any rate, we do assume that in the past things happened as they do now; water dissolved some substances but not others; gravity and light and chemical processes acted then as they do now; gold has always been heavier than iron and it has always been more resistant to acids. It is these observed consistencies that give us a clue to what the world was like, probably, thousands and millions of years ago—if we assume that consistency itself is permanent.

Has Life Always Existed? Year after year we may see fish hatch from eggs, and oaks grow from acorns. Without examining every single fish or every single oak, we say, "Life comes from life". Probably everyone has asked, more or less seriously, "Which came first, the hen or the egg?" Many reasonable answers may be thinkable. We are unable, however, to test such answers in a scientific way. We cannot get back to the beginnings and observe what happened. Records of the past are incomplete. One of the easiest ways to dispose of the hen-and-egg question is to say that there is no problem. If we assume, for example, that the different kinds of plants and animals have *always* existed, we make it unnecessary to decide which came first, or whether there was ever a time when living things did not exist.

There is something to be said for that view. When we look about us, we are impressed with the constant repetition of particular events. Night follows day, the seasons roll on year after year, the planets swing around the sun, again and again and again. Birth, growth, death, and decay follow over and over and over. When we look more closely at the materials of the world, we see constant transformations in endless cycles. Every speck of water moves from the clouds to the earth, from the earth to the oceans, from the oceans to the air, and again into the clouds, endlessly. A particle of carbon goes from the air into the solid structure of a plant, from wood to the fire. Or it goes from a bit of starch in a potato into the blood of an animal, into some brain



FOR EVER AND EVER

From our limited experience we conclude that eggs and hens alternated for many, many years before we arrived, and that they will continue to alternate long after we are gone. Looking forward we see world without end; looking backward we see world without beginning. That illustrates about all we mean by always, and about all we know of natural law

perhaps, and there burns up and eventually returns to the atmosphere, having furnished energy for the happy thought of a poet. All our knowledge, all our certainties, come in fact from our experience with *repetitions*. What happens the same way again and again and again gives us our feeling of constancy, order, permanence. Things are and they continue to be the same—yesterday, today, and forever. We cannot imagine a time when things were really different, except in detail. With respect to plants and animals specifically, like produces like. We see no exceptions, and we conclude that it must always have been so.

Yet, from a study of the earth's crust and from a study of what is happening to stars and planets, we know that there must have been a time during the formation of the earth when the temperature was too high for life. The water was probably in the form of vapor, so that the earth was also too dry to support life. No food was available. Sometime later—many many thousands of years—living things were present. The scientist wonders what happened during that interval, for it was then that "life" began upon this earth.

Life from Afar One theory supposes that the first living germs came floating through space from other planets, and found upon the earth a favorable habitation. Life germs took hold, and in time took on the many forms of plants and of animals. We can imagine spores small enough to be carried through space, pushed by beams of light—some of them falling at last upon the earth and establishing themselves as living protoplasm. This theory has to meet many difficulties. These are: the intense cold in the empty space beyond the earth, the absence of moisture, the extremely long time that it would take anything to come from the nearest system beyond our sun, and perhaps the destructive effects of the ultraviolet light.

To assume that life came from some other galaxy or solar system is merely

to push the problem back a few million years. This theory tells us nothing about how living matter could have arisen in the first place. It accepts the appearance of life as of one date rather than another. A further difficulty with this theory is that it tells us nothing about particular forms of life. It merely offers a "germ" or "spore", which in due course came to be this species and that species and another species.

We cannot harmonize what we know of the earth and its past and what we know of other bodies in space with the idea that life has "always" existed, nor with the idea that it came in some form from another world.

How Can We Know about the Beginnings of Life?

Two Distinct Questions We know that a particular robin or radish came from a particular egg or seed. When we ask how *life* started, we raise two distinct questions.

Sometimes our question means, What is the origin of particular species—horses, for example, or oaks? This question is a scientific one, for it has to do with facts: When did bees first appear, or seed plants? We can compare similar plants and animals from different regions. We can compare similar forms that lived at different times in the past. From the facts so gathered, we can infer a coherent, even if incomplete, story of events, just as the historian or the detective pieces together bits of evidence into a consistent, although incomplete, story of "what must have happened". We may thus reasonably attempt a scientific answer to the question "How did different species arise?"

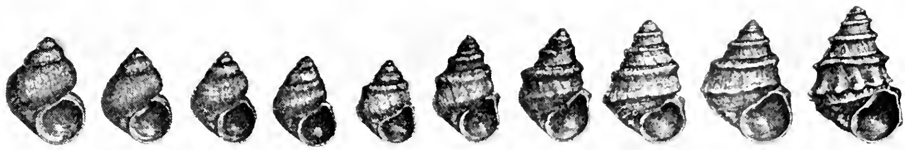
Sometimes, however, our question as to the origin of *life* refers to that peculiar something about all plants and animals which somehow distinguishes living things from all others. This is a question about which we can speculate or argue, but not one about which we can readily make experiments or observe conclusive facts. The very question presupposes that life exists apart from living objects or apart from matter and energy. The question is in some ways like the question What becomes of the reflection in the mirror when the lights go out? or What becomes of your lap when you stand up?

Vitalism All that we know about life is what we know about living plants and animals. We know that animals and plants assimilate food and grow, that they respond to external disturbances by movements and by chemical changes, that they reproduce themselves. We sum up what we know about millions of plants and animals by saying—for convenience only—life increases in amount, life responds to changes, life reproduces itself.

We can study more closely the activities of particular living things. We can then break some of the facts down into simpler and more familiar facts. We can see that solution, osmosis, oxidation, evaporation, diffusion, and other physical and chemical processes go on in organisms. We are confident, from

JUDGING THE AGE OF THE ROCKS

We can see rivers cutting gullies through layer after layer of soil and rock. We assume that rivers produced gorges and canyons in the same way through the ages. We can see lakes, and even the seashore, filling up with silt. We assume that the upper layers of mud and rock are more recent than the deeper layers



LATER SPECIES DIFFER FROM THEIR PREDECESSORS

Thousands of pond-snail shells dug out of mountains in Slavonia, at different levels, were arranged in order from the oldest to the most recent. They showed increasing departure from the oldest type; and the most recent resembled most closely the forms still living in the mountain lakes

our studies, that the total energy output of an organism balances exactly the total energy income. Similarly, we find that the total material growth and output of a living thing balances exactly the material income. From a purely physical or chemical point of view, "vitality" is neither a particular kind of matter nor a particular kind of energy. Yet we are sure that a living organism *is* different from the same organism dead.

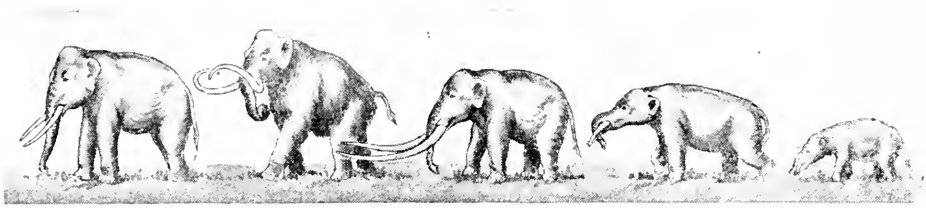
While we are thus unable, in a strictly scientific sense, to locate or manipulate any *vital principle*, many nevertheless choose to "believe" that there is such a something. For it is often convenient to explain what happens *as if* such a principle were actually at work. In the past scientists spoke of caloric or of phlogiston to explain various happenings or appearances associated with fire and heat, just as in earlier times "spirits" explained sickness, thunder, and other mysterious happenings. This is not to say that a vital principle does not exist. It is to say only that when we do choose to believe in something of this nature, we owe it to ourselves to recognize that we are dealing with a *supposition*, or hypothesis, not a *fact.*

Did Life Originate from the Not-Living?

The Scientist's Dilemma[1] Scientists reject the sun myths and ocean myths of ancient times. They treat modern tales of the "spontaneous" transformation of rubbish and dirty water into worms or mice as examples of false inference or of faulty observation. Nor will most scientists admit that life has "always" existed on the earth or that it came into being through a "miracle". That is, we cannot admit that there has ever been any violation of those orderly relationships between substances and forces which we call the "laws of nature". Nevertheless, scientists are obliged to assume that life originated from nonliving matter. Life did and still does so originate.

Life out of Nonliving Through photosynthesis lifeless water and carbon dioxide become starch and sugar. Through the oxidation of sugar chemical

[1]See Nos. 2 and 3, p. 449.



SPECIES LIVING TODAY DIFFER FROM THOSE OF THE PAST

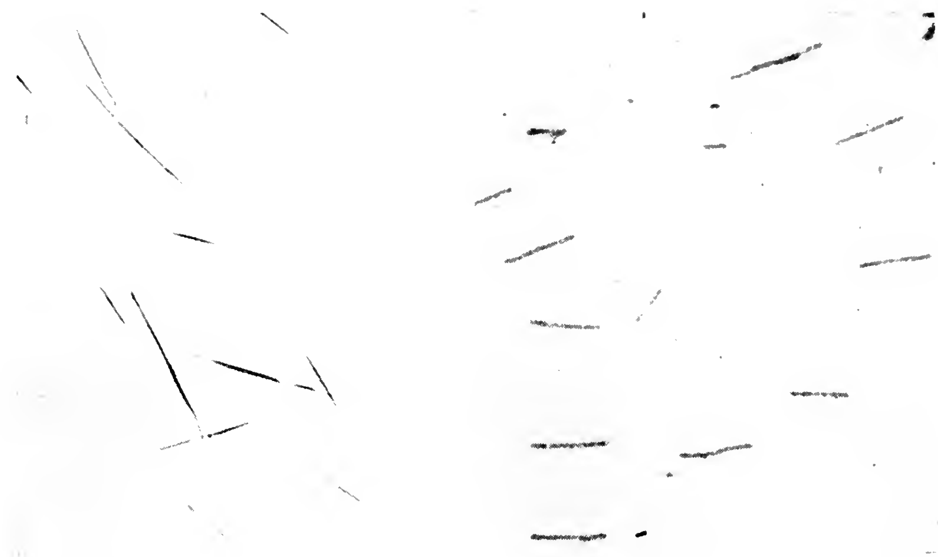
Just as there are many kinds of bears or bananas living today, the fossils show us that there were in the past many kinds of plant and animals which strongly resembled present-day species, yet differed from them in many ways

energy becomes muscular action. It is true that lifeless matter is transformed into starch and into muscular action only by existing organisms. But in the course of a century chemists have been converting such lifeless matter into more and more complex carbon compounds and nitrogen compounds of kinds that have not been found in nature except as parts of plants and animals (see page 99). Lately chemists have made synthetically compounds related to proteins and have even duplicated compounds of the vitamin and hormone type.

In recent times chemists have shown that under certain conditions of temperature and light and dilution, some of the simpler "organic" molecules arise "spontaneously". These conditions set up in the laboratory are probably like those that existed ages ago before there were any organisms, when the oceans were warmer and less salty than at present. These facts make it seem reasonable to suppose that there first appeared various molecules of sugars and proteins and fats—substances that are basic in protoplasm. Such compounds by themselves are not, of course, living. Yet combinations of such compounds behave in ways that suggest "life".

These findings of biochemists support the hypothesis that compounds, becoming more and more complex, lead in time to mixtures and combinations that approach the living. We cannot say that life arises spontaneously at a particular time. But it is reasonable to think that over a long period life evolved out of forms of matter which had not existed in earlier stages of the earth's history.

Between Living and Nonliving On the basis of his "germ theory" of communicable, or infectious, diseases, Pasteur managed the dramatic cure of little Joseph Meister, bitten by a mad dog. He was unable, however, to find the "germ" of *rabies*, and concluded that it was too small to be seen with any microscope. Later it was found that this virulent or poisonous something would pass through the pores of a clay or porcelain filter, which are too small to let the smallest visible particles pass through. By the end of the century a number of "filterable viruses" were known to cause infectious diseases. In



Wendell M. Stanley and *Journal of Biological Chemistry*

BETWEEN LIVING AND NOT-LIVING

Seen through an electron microscope (right), tobacco-mosaic virus suggests "microbes". Yet it seems to have definite chemical composition, since it crystallizes like a non-living salt (left), although, like living protoplasm, it is able to assimilate foreign matter

this group of diseases are hoof-and-mouth disease of cattle, yellow fever, smallpox, measles, mumps, influenza, encephalitis, infantile paralysis, and the so-called mosaic diseases of tobacco and other plants.

Like living bacteria, a virus may increase in quantity by feeding at the expense of other substances—in the case of the mosaic diseases, the materials of a living plant or animal body. A virus thus grows and reproduces itself, becoming more and more. In some respects, however, a virus behaves like a large molecule of protein. It has no discoverable structure, such as the simplest of plants and animals have. A virus seems thus to be a distinct chemical substance which may form crystals, and may conceivably arise without the previous action of life. And yet such a substance shares some of the characteristics of living matter.

In 1918, the Canadian Félix d'Hérelle (1873–   ), a bacteriologist, started an investigation on just what happens to overcome the living bacteria when a person recovers from dysentery. D'Hérelle separated out a substance that destroys and actually dissolves the bacteria. He called this something *bacteriophage*—that is, "bacteria-eater". Unlike the antibodies formed in an organism reacting to bacterial infections (see pp. 232–234), bacteriophage can increase in quantity outside the body of the host. D'Hérelle, and later others, fed masses of bacteria to bacteriophage in glass dishes and so increased the quantity of the substance.

Later it was found (1) that there must be several kinds or strains of bacteriophage, each one specific for a particular species of bacteria, and (2) that bacteriophage will not attack dead bacteria. It is not yet certain whether bacteriophage could increase apart from living bacteria which it eventually destroys, just as living organisms can grow in an artificial broth. From chemical studies, however, it appears that a bacteriophage resembles a virus; that is, it is a "substance" rather than an "organism", although it behaves in some respects like a "living" something.

Many chemical compounds that have been produced synthetically resemble in their behavior complex protein molecules in living things. We cannot call these substances living. But we can at least imagine that under certain conditions combinations of such unstable molecules bring about a new system, which interacts with other substances as does a virus or a bacteriophage. That is, each makes more like itself out of substances that are different; it *assimilates*. But we are still far from creating life in a test tube. Indeed, the more we find out about these complex molecules, the less hopeful we are of duplicating any of nature's living beings artificially.

Like the theory that life comes from another planet or another solar system, the theory of spontaneous generation is concerned with the origin of life in general. It has nothing to say about the beginnings of particular plants and animals. It assumes that whatever makes it possible for living matter to arise from nonliving matter makes it possible also for new forms to develop further with changing conditions. The theory of spontaneous generation thus has a variety of meanings. It depends upon the way we formulate our question and upon what we assume about the nature of the world or about what makes things happen.

Our Limited Knowledge If a plant or an animal should some day arise "spontaneously" out of "nonliving" material, we should be quite unable to know about it. Even if a "worm" should crawl out of a lump of mud under our very eyes, we could not tell whether it had developed from an egg or from a grain of sand. All we can say is that, under strictly controlled experimental conditions, nobody has yet seen any evidence of "spontaneous generation". That is, *we cannot "prove" that spontaneous generation is impossible.* We can say only that we have experienced no clear case of it. We are therefore unable to say in advance what may or may not appear from further studies and experiments.

Did Various Plants and Animals Arise at the Same Time?

Special Creation What happened between the early period when there was no life on the earth and the later period in which there was life? Something extraordinary must have happened, that is, something that is not fa-

miliar to us. We cannot really *know*. Accordingly, some persons frankly ascribe the beginning of life upon the earth to a "miracle", a direct act of "creation". In different stages of civilization, among different types of people, this miracle was described in different ways. Sometimes these descriptions involve religious ideas and sentiments. Sometimes they are straightforward attempts to explain the world as a natural process. It is interesting to compare these different explanations, although they tell us less about how the world and life originated than they do about how the human mind thinks.

For certain purposes it is convenient to suppose that all species were created at about the same time, and that each species has remained from the beginning exactly as we now find it. For "like produces like". This was, in fact, the assumption of Carl Linnaeus, the great Swedish naturalist (see page 34). This point of view leaves many questions unanswered, but it is not in itself impossible. Indeed, it is the most common view among the populations of Europe and America.

In one form the direct-creation theory supposes that every detail which we can observe was made just as it is to fit into some general scheme. In another form the theory declares merely that the universe was so created that in due course it brought about life of various forms, and in time man himself. According to this view, which was held by Saint Augustine, Christian scholar of the fifth century, the creation did not finish making the world and its inhabitants; it merely started things off on a long course of constant change. Everything that has happened from the beginning has followed naturally and automatically from the way the world was made to go.

Many Creations A still different conception of the creation miracle was proposed by Georges Cuvier, the great French naturalist (see page 176). According to this view, the many different forms of life that have inhabited the earth at various times were separately created. Each new species was unrelated to any that had existed before. In the course of time, too, some of the species died out. All the great changes in the history of the world which we infer from a study of the crust of the earth, Cuvier explained as the results of special violent events, or cataclysms—inundations, volcanic eruptions, earthquakes, and the like.

Cuvier and Saint Augustine seem to have been better informed than Linnaeus concerning the great changes in the earth's inhabitants that evidently took place through the course of ages. They agreed with Linnaeus, however, that the parade of living things was started by an act of creation. Cuvier did not agree with Saint Augustine on one important point. Whereas Saint Augustine thought that the creation set going a process in the course of which new species eventually arose, Cuvier thought that new species were being created from time to time, following earlier forms but not descended from them (see table on page 448).

Classic Views on Creation and Evolution

<table>
<tr><th>SAINT AUGUSTINE</th><th>GEORGES CUVIER</th><th>CARL LINNAEUS</th></tr>
<tr><td colspan="3">Agreed that life arose as a special creation</td></tr>
<tr><td colspan="2">Species of plants and animals inhabiting the earth have changed through the ages</td><td rowspan="2">Species have remained in time exactly as they were created</td></tr>
<tr><td>Creation included the processes by which new species arose from previous forms</td><td>Each species was created anew from time to time, without relation to previous forms</td></tr>
</table>

All these theories, whether or not they involve miracles, resemble scientific hypotheses in assuming or supposing some agency or process that could reasonably account for the facts to be explained. But these views differ from scientific conceptions in one important respect: they rest on assumptions that cannot be checked or tested by further facts. The scientist tries to shape his theories in ways which will permit them to be checked by further observations or experiments. Obviously we cannot make any experiments regarding what happened millions of years ago. But the scientist can do one of two things. Either he can say frankly that he does not know or that he cannot imagine. Or he can think out "explanations" or suppositions that not only are "reasonable" but that enable us to experiment with materials and processes and events that are at hand now.

In Brief

To talk about the "origin of life" implies that life exists apart from matter and energy.

It is impossible, in a strictly scientific sense, to locate or manipulate any "vital principle".

What we know of the earth and its past and what we know of bodies in space can be harmonized neither with the idea that life has always existed on the earth, nor with the idea that it came in some form from another world.

In the laboratory, complex compounds have been made which approach the make-up of various substances that occur naturally only in protoplasm.

Filterable viruses and bacteriophage behave in some ways like living beings, yet appear to be chemical compounds rather than organisms.

Many distinct yet plausible explanations of the origin or creation of the world and of life have been developed by peoples in all parts of the world and in all stages of civilization.

Some of the creation theories assume beings or forces about which we can have no positive knowledge.

Science is not primarily concerned with disproving beliefs which have served to explain the phenomena of life.

Explanations offered by scientists must be not only plausible, but, in addition, susceptible of being checked against all the facts of observation or experiment.

EXPLORATIONS AND PROJECTS

1 To find out what explanations different peoples have given concerning the origin of life, read portions of Bulfinch's *Age of Fable* or of Frazer's *Golden Bough*. The bibles of different religions or races will suggest other theories of how life began. Have your librarian suggest other sources, such as books on mythology and on the teachings of some of the great philosophers and religious leaders.

2 To see whether we can get micro-organisms to arise spontaneously in dead organic matter, expose some sterilized bouillon where nothing can get to it from the air, and some under ordinary atmospheric conditions. Compare after a few days or a week. Describe changes that indicate the presence of living matter in either or both of the flasks.

3 To determine whether maggots (fly larvae) develop spontaneously, expose meat where flies cannot get at it, but where the air can. Place some meat in the bottom of each of three jars; leave one open; cover one with fine gauze and the third with parchment. Keep near an open window or where flies abound. After a week or so, examine each jar carefully; compare results and explain any differences.

QUESTIONS

1 How do we derive our information about life?

2 In what respects are questions about life essentially different from our questions about particular living things?

3 What evidence is there that life has always existed? that it has not always existed?

4 What evidence is there to show that life has always remained the same? that it has changed?

5 What explanations have been proposed of the origin of life? What kind of evidence have we to support or refute these explanations? What chance is there of proving with certainty the truth or falsity of any of these various explanations?

6 In what respects are certain laboratory compounds of organic material like protoplasm? In what respects are they different?

7 What kinds of answers are possible for questions about the origin of any particular individual or species? for questions about the origin of life as distinct from nonliving matter? How do answers to the first question help us in answering the second?

1. How many different kinds of species are there?
2. Has the number of species always remained the same?
3. How can we tell how long there has been life on the earth?
4. Were there ever forms of plants and animals that no longer live?
5. How can we tell that some of today's species came into being later than others?
6. What could make a species of plants or animals die out?
7. How can we tell that fossils were produced by living things?
8. How can we tell that some fossils belong to an earlier period than others?
9. How can plants or animals of different kinds be related?
10. How can a plant or animal be descended from a different species?

Inside a "time capsule" objects might remain "unchanged" for centuries. A living plant or animal, however, could not remain exactly the same for very long. For an organism is essentially a system of constant changes; it can continue to be itself only by changing from moment to moment. An organism grows, develops, matures, reproduces, and finally dies. In the world of life there are (1) cyclic, or repetitive, changes, as in breathing, the circulation of the blood, or the succession of new but similar individuals from generation to generation as each species reproduces itself, and (2) developmental, or progressive, changes, through which a living thing becomes different from hour to hour or from year to year.

Much of what happens in the world is of cyclic nature—day and night, ebb and flow of tides, the seasons, erosion and sedimentation. There is also a historical process, a certain continuity of change for the world as a whole. The earth itself has undergone changes through the centuries. How can we tell that the forms of life have also changed? Is evolution still going on? How can we tell?

How Can We Tell What Kinds of Organisms Lived in the Past?

Digging into the Past[1] Digging into the earth for all sorts of purposes, men have come across various unexpected finds. They have found buried treasures, ruins of cities, wrecks of automobiles, bones of human beings and of other animals. Among the finds which have interested people for centuries are *fossils*—from a Latin word meaning "to dig". These fossils are the most direct evidence we have about the inhabitants of the earth in ancient times.

There have been theories to explain the existence of fossils and their pecul-

[1]See No. 1, p. 470.

GEOLOGIC ERAS	GEOLOGIC PERIODS	MILLIONS OF YEARS AGO	FIRST APPEARANCE OF NEW TYPES OF LIFE	DOMINANT LIFE FORMS
Cenozoic (Tertiary, Quaternary)	Recent		Modern man	
	Pleistocene		Primitive man	
	Pliocene	1	Man-like apes	
	Miocene			
	Oligocene			
	Eocene			
	Paleocene	60	Primates	
Mesozoic	Cretaceous		Placental mammals	
	Comanchean			
		135		
	Jurassic			
			Marsupials	
	Triassic			
		180	Mammal-like reptiles	
Paleozoic	Permian			
	Carboniferous: Pennsylvanian		Primitive reptiles	
	Carboniferous: Mississippian		Amphibians	
	Devonian		Fishes	
	Silurian		Fish-like vertebrates	
	Ordovician			
		450		
	Cambrian			
		550		
Archeozoic, Proterozoic	Precambrian		Invertebrates	
		1200		
		2000		

NEW LIVING TYPES IN SUCCESSIVE DEPOSITS OF THE EARTH'S CRUST

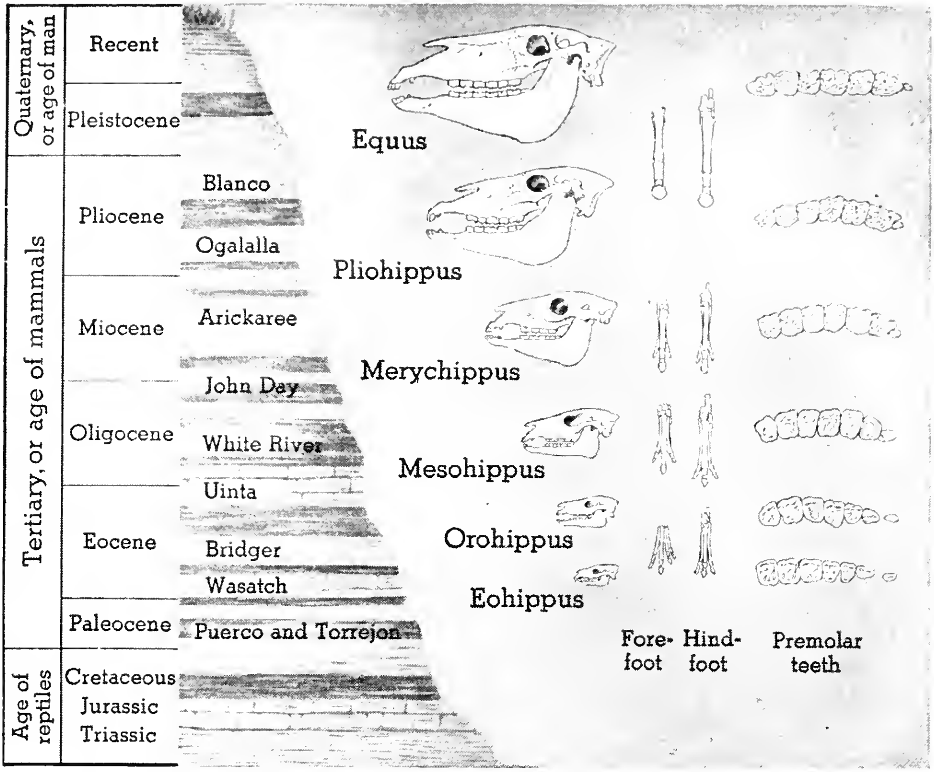
iar forms. Fossils were merely freak resemblances to plants or animals. Nature could make rocks of any shape, like crystals, or like a leaf, or a queer bird, or an old shoe—why not? Perhaps nature had tried out various forms before deciding on the kinds to be produced in quantity; fossils were the experimental models that had been rejected. Leonardo da Vinci (1452–1519), the great artist and engineer of the time of Columbus, took them to be the remains of ancient life.

The great objection to da Vinci's view was that many mountain fossils obviously resembled sea animals. How could sea-shells and the bones of ocean fish get up into the mountains? Da Vinci's view is today supported by vast numbers of facts. And today we know that in the course of millions of years the surface of the earth in any region may have been alternately under the floor of the ocean and high up in the mountain levels.

Students of fossil structures naturally tried to classify them and to compare them with existing plants and animals. Many resemblances were found between the organisms of the past and the organisms of the present, but also marked differences. Assuming that the relative ages of fossils correspond to their relative positions in the layers of rocks, we find that forms that are intermediate between the most ancient and the most recent are also intermediate in structure (see illustration, p. 443). One of the best examples is seen in the horse and his probable ancestors (see illustration opposite). Similar series of fossils have been worked out for the elephant in Africa, for various fishes in England and elsewhere, and for many lines of birds and reptiles in all parts of the world. A remarkably complete series was found in Germany, showing successively different types of snails, leading down to the forms existing today.

Pickled Fossils Since the time of Cuvier, who founded the science of comparative morphology, scientists have been "reconstructing" ancient life forms from fossil fragments. In many cases there are only fragments of skeletons, sometimes only fragments of bones. Reconstructions are necessarily based on inference, since there is no way of "proving" the guesses as to how these ancient plants and animals really looked. But early in this century John C. Merriam (1869–), an American paleontologist, found a remarkable collection of *complete* skeletons of animals that must have lived from fifty to a hundred thousand years ago. Near the present site of Los Angeles an old "tar hole" at Rancho La Brea was being worked for asphalt. Almost daily the workers observed that chickens, squirrels, and various other birds and small mammals would get entrapped in this brea, or tar. And as these animals struggled to escape, they attracted larger predatory mammals, which in turn would also be swallowed up in the asphalt.

The workers, digging deeper and deeper, would bring out, with the asphalt, remains of old trees (which made very good firewood) and thousands upon



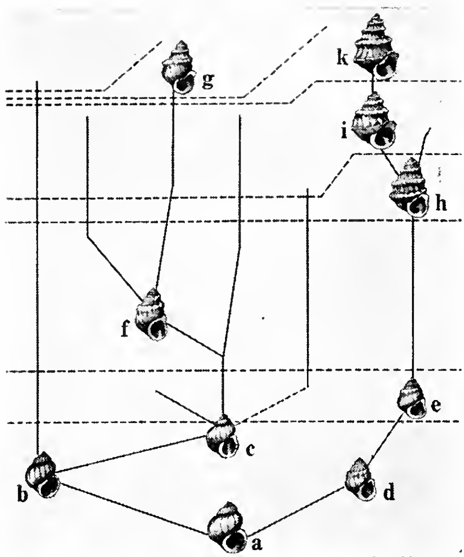
After Matthews, American Museum of Natural History

ANCESTORS OF THE HORSE IN AMERICA

The oldest of the fossils do not resemble the corresponding parts of the modern horse very strikingly, but with each succeeding age the skulls, the bones of the feet, and the teeth resemble those of the horse more and more closely

thousands of various kinds of bones. They recognized some of these bones as coming from familiar animals, such as were currently being swallowed up in the tar. From lower depths, however, there came bones which nobody could recognize. At last, when it was no longer profitable to work the bed, scientists got their chance. They brought up probably several million bones, which they began to clean and put together.

A remarkable thing about these unmistakable bones was that they represented forms of life which no human being had ever seen on this continent. There were gigantic members of the cat family, lions and saber-toothed tigers, large bears, mastodons, elephants, camels, extinct types of horses, wolves, and bisons. Any doubt that fossils were really the remains of animals and plants that at one time lived upon the earth is definitely cleared up by the bones from Rancho La Brea. If the facts are unmistakable, however, there is still room for argument about their interpretation.



After Neumayr

These and many other varieties of snail fossils are distributed through the rocks in Slavonia as if they were descended from common ancestors. Forms (b) and (d), for example, resemble (a) more than one another; (c) is more like (b) than any of the others; (e) is more like (d); and so on. Fossils resemble most closely those in the nearest layers above or below. If we should find these forms scattered over widely separated areas, experts would undoubtedly consider them as distinct species. Only one reasonable explanation has been suggested for the distribution of these shells in the various layers and in the regions of the entire area, and that is that descendants have come in time to differ more and more from their ancestors

DIVERGENCE RELATED TO TIME

Refrigerated Fossils Paleontologists and morphologists had reported the ancient existence of mammoths, animals supposed to resemble the elephants of India, but having shaggy wool and very long, slender and curled tusks. But nobody had ever seen such an animal. There were indeed pictures of such animals on the walls of caves in France, made presumably by prehistoric man (see illustrations, page 57). Scientists inferred the former existence of this type of animal from fossils picked up from time to time in various parts of northern Europe and northern Asia. They inferred a great deal about the size, the form, the mode of life of this animal. For many centuries the natives in parts of Siberia had made quite a business of digging up bits of the tusks and selling them to the Chinese, who made carved ivory ornaments of them. But nobody had ever seen a mammoth. There had been no "history" or tradition to tell us of such animals.

Early in this century Russian explorers in northeast Siberia found buried under many feet of ice a *complete mammoth.* This animal had apparently fallen into a crack in the ice, had been covered by snow, and had been frozen solid. So well preserved was this animal that the blood in the veins and arteries could be thawed out. The contents of the stomach could be identified as made up of grasses and other plants of the region. And when the flesh was thawed out, it was eaten by the dogs. Since then, some two dozen more such perfectly preserved mammoths have been found in the frozen swamps.

Interpreting Fossil Facts[1] Some strange petrified bones that had been dug up from under the streets of Paris were brought to Georges Cuvier. At

[1]See No. 2, p. 470.

once he declared the bones to be those of an elephant. It was not the kind of elephant, from Africa or from India, that one sees at a menagerie, but a kind of elephant nevertheless. But there are no elephants in the region of Paris! That is true, Cuvier admitted; but at one time there must have been. And none of their descendants are living today. Cuvier believed that the earth had several times been cleared of its living inhabitants, and repopulated by a new set especially created—that the elephants of today resemble certain elephant-like animals of the past, but that they are in no way related. Others find it easier to imagine that the life of today has *descended* from the life of the past.

How Can Different Species Be Related?

Resemblances and Relationships The historical idea of plant and animal species is that the members of a species are all descended from the same ancestors. But in describing a species we have assumed relationship, or common

Carnegie Institution of Washington

BONES FROM THE CALIFORNIA TAR PIT

Among the bones removed from the tar pit at La Brea were many belonging to animals that are not known to be living anywhere today — saber-toothed tigers, mastodons, species of camels, extinct horses and various birds and small mammals

Painting by Charles R. Knight, from American Museum of Natural History

HAIRY MAMMOTH

Scientists could not "prove" their guesses about the characteristics of this animal, or even about its existence some 100,000 years ago, but for the rare chance that some of these giants had been caught in the swamps and had been preserved in the frozen state — and were then dug up by men who had the wit to piece the story together

ancestry, on the basis of resemblance (see page 36). That is, we see and handle only individuals, but if several are enough alike for us to consider them of the "same kind" or species, we call them by a common name and *take for granted* a common ancestry.

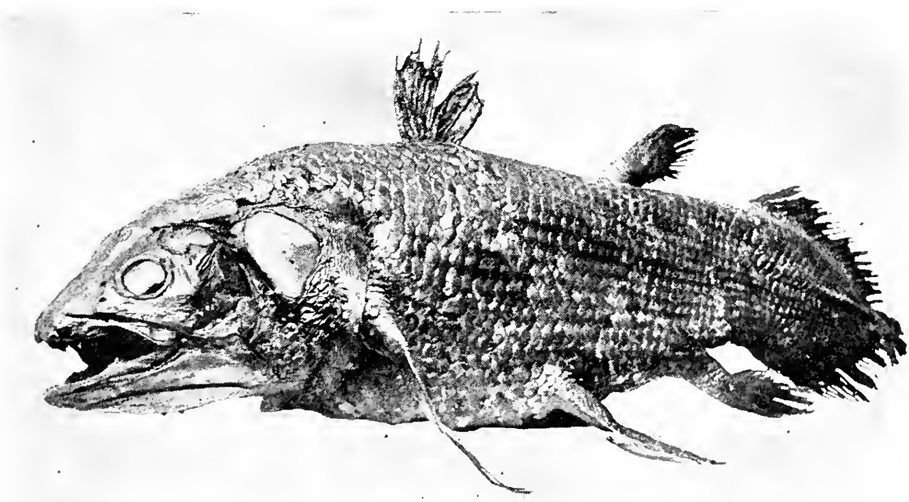
Now, according to the older idea of Linnaeus and others, each animal species and plant species is distinct from all the others, and came into existence independently. It "exists" in the same sense as a particular individual exists. But arranging plants and animals according to degrees of resemblance leads to a grouping of species into genera, of genera into families, of families into orders, and so on into larger and larger assemblages (see page 38).

The characteristic "branching-tree arrangement" of all the kinds of living things recalls the arrangement of individuals in a "family tree", where the relationships are known. This similarity naturally suggests that different classes and orders and genera of plants and animals are related to each other as are members of a species, namely, in the sense of having descended from common ancestors (see frontispiece). Indeed, Linnaeus, in the first edition of his great work, treated the "genus" as if it represented the original ancestor and the species as mere variations on the theme.

The differences between the species in one genus are often trivial as against the resemblances between two genera. Species must be "related" in the same sense as cousins are related. The only question is, How far back in the family tree can we find "common ancestors"? Our classifications suggest that if we go back far enough, we may find that ducks and geese are related; or that *all birds* are related; or that *all fishes* are related—that is, descended from the same ancestors. If we go back still farther, we may find that all backboned animals are descended from the same ancestors.

There is no reason in advance against assuming that each species has been separately created, or has otherwise arisen independently of all others, as have artificial objects. If that were true, however, we might reasonably expect to find, among the million or more distinguishable forms, at least an occasional species that stood out by itself. It would be like a special commemoration stamp, or some freak "gadget", which differs in its design from all its contemporaries. However, we find no such unique cases among organic species. Even when we classify the extinct forms, we find that they fit logically into the same general branching arrangement of living forms.

Measures of Resemblance If we compare various insects, for example, we shall find that most of the functions are carried on by corresponding organs in the different animals. Thus the locomotive organs in bees, butterflies, and grasshoppers are the legs and wings; and in every case the relative position



A LIVING ARGUMENT ABOUT FOSSILS

In 1939, off the coast of Africa, a living, breathing, scrapping Coelocanth was brought up from the depths in a fishing net. He did not live very long, but long enough to indicate that certain fossils found in old rocks correspond closely to an armored fish that did actually live, although considered as long extinct

of each organ and the general plan of structure are the same. If we examine the mouths, we shall again find many basic similarities, in spite of the great differences.

The questions raised by these facts may be clearer if we compare the insects in general, let us say, with backboned animals. We call the walking organs of insects and those of frogs or mammals "legs". But these legs are not all built on the same plan, although they have numerous resemblances. Moreover, the flying organs of butterflies and those of birds are quite different in their plans and in the arrangement of muscles (see illustration, p. 18). This comparative study, which shows us the similarities and differences in every detail of the structure of organisms, is known as *morphology*. The resemblances thus disclosed are even more remarkable than the superficial ones obvious to the casual observer.

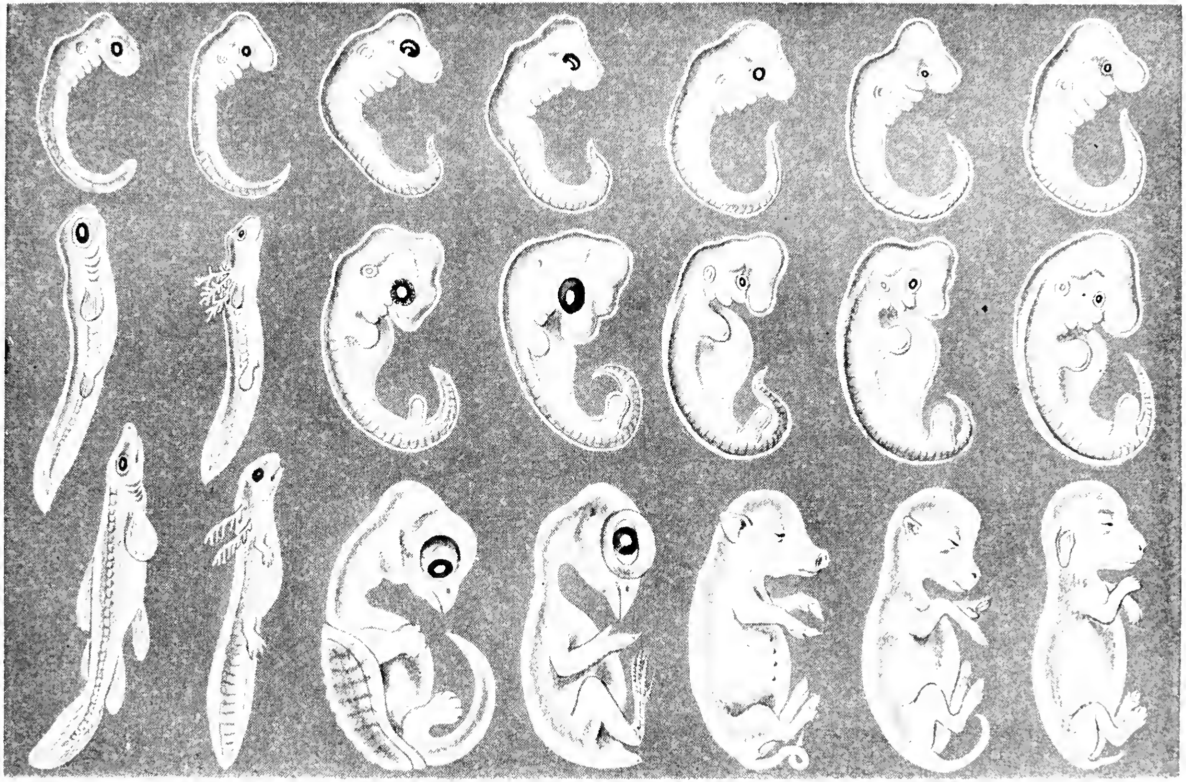
Homology Among animals that are built on substantially the same plan, the corresponding parts are said to be *homologous*. Thus the thorax of one insect is homologous with the thorax of another insect. Or the liver and teeth and hair of a dog are homologous with those of a bear.

Most striking, perhaps, are the homologies so evident in the skeletons of the vertebrates. In each, the axis consists of a series of similar-shaped hollow bones, through which the spinal cord extends. At the front end is a bony cranium which completely incases the brain. The ribs are similar in shape and attachment. If we limit our comparisons to the mammals, we find an amazing similarity in the number and arrangement of the bones in the fore limbs and hind limbs, and in their attachment to the spinal axis. At the base of the spine is a ring of bony structure, called the *pelvic* girdle, to which the hind limbs are attached. The fore limbs are connected by a similar set of bones, spoken of as the *pectoral* girdle (see illustration, p. 49). It is difficult to account for these homologous structures unless we assume that the organisms have a common ancestry.

Analogy Structures of different type, or belonging to different types of organisms, but carrying on similar functions, are said to be *analogous*. Thus the jaws of a grasshopper may be considered analogous to the jaws of a cow. They are not homologous.

When we compare plants with animals, we often find similar functions carried on by organs that are so different that it is not easy to decide at once which organs are "analogous" in the two forms. Many plants, for example, have no special breathing organs that are strictly analogous to our nostrils or to the spiracles of insects, for they may absorb oxygen from the air at any part of their surface, as do most "worms". And as for homology, most people never discover any at all between plants and animals.

Resemblances in Development We have seen that in the course of a lifetime each individual passes through a series of more or less distinct stages



STAGES IN DEVELOPMENT OF VERTEBRATES

Individuals of different species are most alike in the egg stage. As they develop, they become more and more unlike their early stages, and also more and more unlike each other. In the end each species is distinct

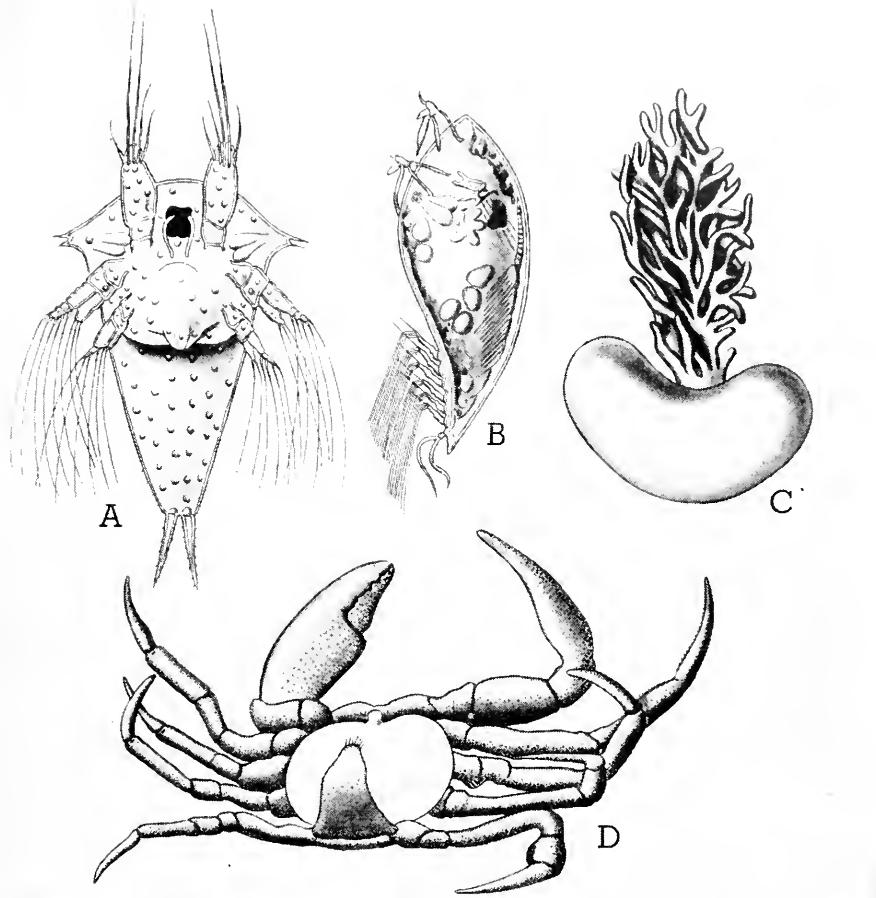
(see page 347). And we have seen that the farther back we go toward the one-celled stage, the more and more do these stages resemble corresponding stages of other species. Thus in the life history of a mammal there are structures that suggest stages in the life history of birds and of fishes (see illustration, p. 459). The larvae of different kinds of mosquitoes are more alike than the larvae of mosquitoes and beetles; the larvae of insects in general are more alike than the larvae of insects and crabs, and so on (see page 355). Now the most reasonable explanation of such facts is the supposition that there is a common (or similar) development just to the extent that organisms are "related" through having descended from common ancestors.

Useless Structures Relationship is further inferred from the fact that in plants and in animals certain organs persist through whole groups, although they are quite useless from the point of view of adaptation. For example, the whale develops legs that are never used, and the same is true of certain snakes. The skeleton of many a bird shows distinct signs of fingers, or claws, among the wing bones. The vermiform appendix (see illustration, p. 175) in man has been interpreted as the lingering remains of an organ that developed and took part in digestion in other backboned animals. It has no practical meaning in the life of man today—except to make trouble sometimes. We can understand such examples readily if we suppose that all plants and all animals are related through having had common ancestors. No other theory that agrees with all the facts has been suggested to explain such "vestigial" structures.

Geographic Distribution We expect every group of organisms to expand its range just as far as conditions permit. And we rather expect a given kind of situation to maintain one kind of population and a different kind of situation to maintain a different kind of population. Yet when we examine the distribution of species over the surface of the earth, certain curious facts appear.

Regions in every way similar, as to climate, soil, and so on, are inhabited by totally different plants and animals. Thus the climate of Australia is not very different from that of most of Europe and large parts of Africa, Asia, North America and South America, yet Europeans who first came to Australia found plants and animals that are not found in these other parts of the world. Many such puzzling differences are found in comparing the flora and fauna (plant and animal populations) of regions that are geographically similar.

On the other hand, regions that are very different in climate, soil, and so on, are occupied by plants and animals that are so much alike that we class them in the same families. Thus goats and sheep, obviously related to each other genetically, occur naturally in the Tropical Zones, as well as in the Temperate Zones, and well up into the Arctic and Antarctic circles, living in many kinds of surroundings.

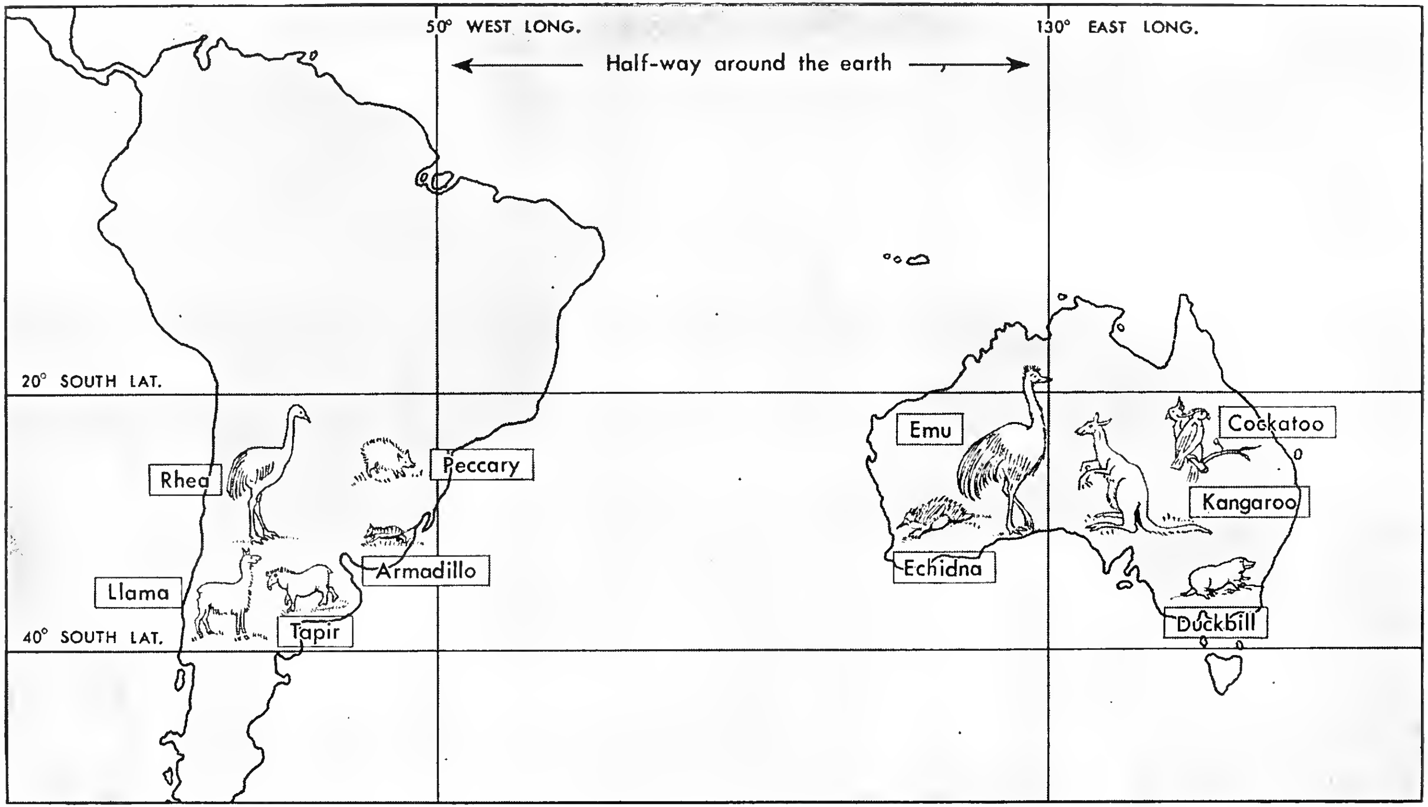


After Gruenberg, *The Story of Evolution*

AN INFANT'S RESEMBLANCE TO ITS ANCESTORS

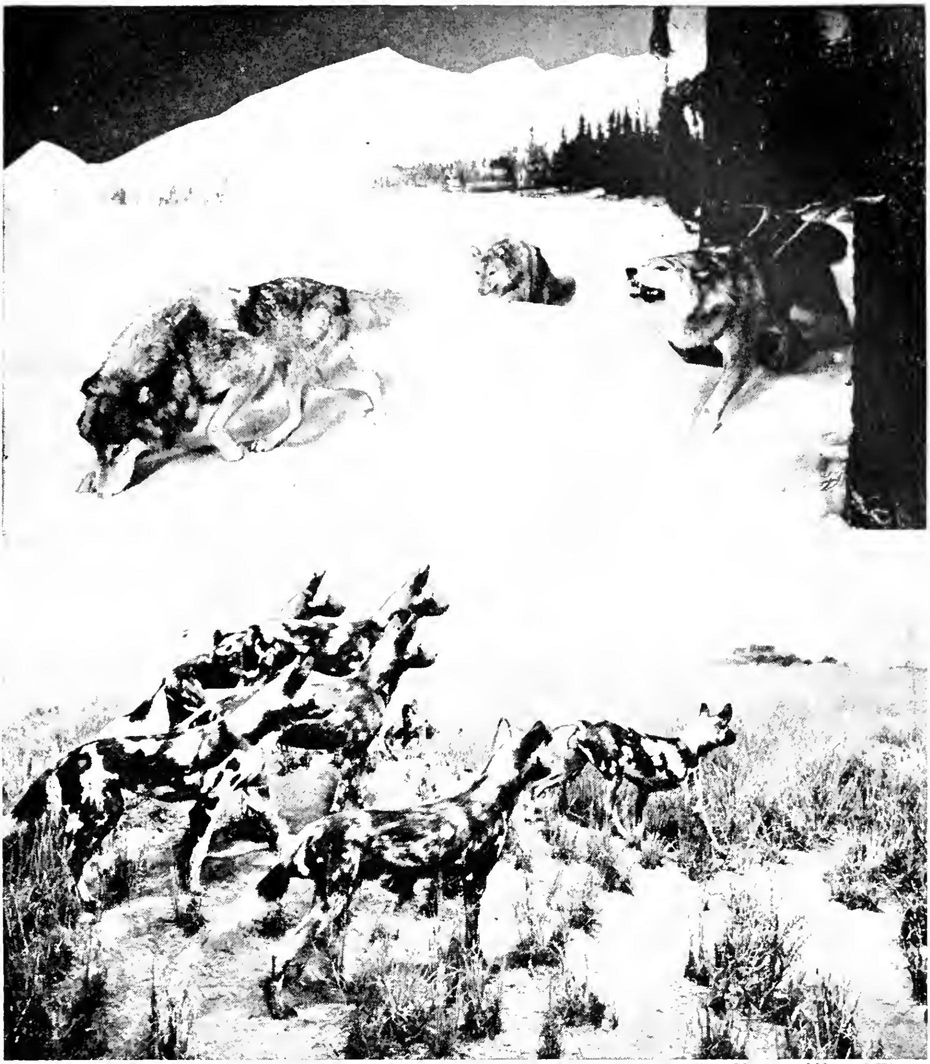
The almost shapeless Sacculina (C) growing as a parasite on the abdomen of the crab (D) has nothing in its structure or behavior to suggest a relationship to its host. Yet in its early development (A, B) it seems destined to become an unmistakable crustacean. Without a study of its life history we should never have guessed that host and parasite are of the same class of animals

Darwin pointed out that similar regions which are occupied by different flora and fauna are always separated from each other by impassable barriers, such as oceans, mountain ranges, and deserts. On the other hand, when regions which differ markedly in climate, soil, and so on are inhabited by similar plants and animals, they are either directly connected at present or show evidence of having been so connected in the past. For example, the plants and animals found on oceanic islands are frequently quite distinct from



DIFFERENT INHABITANTS OF SIMILAR CLIMATES

If we assume that plants and animals normally live in regions to which they are well adapted, how can we explain why the native species are so different in two regions that are equally suitable for the two distinct sets of plants and animals?



American Museum of Natural History

SIMILAR INHABITANTS OF DIVERSE CLIMATES

If each region is inhabited by plant and animal types especially designed for it, we want to know why variations of the same type — dog, for example — occur as timber wolf in the cold regions of North America and as wild dogs in the temperate regions of Africa

those found elsewhere, but they are, as a rule, most closely "related" to the inhabitants of the nearest mainland (with which such islands were apparently connected in the past). Facts of this kind can be explained if we assume that all organisms are derived from ancient forms, with modifications. But they cannot be easily explained in any other way.

Facts and Explanations According to the records preserved in the rocks, in coal mines, in tar pits, and elsewhere, there can be no doubt that the species of animals and plants which inhabited the earth in the past were succeeded through the ages by different species. This is as truly a matter of *fact* as the statement that the men, women and children in a given town have changed in the past ten years, even if the total number remains the same. But while people of ordinary intelligence can grasp and accept the facts, it has been difficult to find an explanation that would satisfy everybody.

We saw that Georges Cuvier, who helped to establish the historical fact that life forms have changed through the ages, thought of the succession of species as *discontinuous* (see page 447). That is, he believed that as existing forms were destroyed in one or another cataclysm, other species were created to take their places.

A different type of explanation was offered by an older contemporary of Cuvier's, the French zoologist and philosopher Jean Baptiste Lamarck (1744–1829). According to Lamarck's view, life has been *continuous* from the beginning, regardless of how living things came to be in the first place. Descendants differ from their ancestors; and when the deviation has reached a certain degree, there is a new species.

These two types of explanation account for the same facts. Both can be supported by good arguments and by further facts. On the whole, however, the theory that there has been *modification with continuity of descent* fits in with more kinds of known facts and calls for fewer special assumptions. This theory does not, of course, answer the question How did living beings originate in the first place? Nor does it, of itself, tell us just *how* modifications have taken place. But it does lend itself better to further experimental exploration than the theory of a new special creation for each species.

Half a century later, when explorers and investigators had brought together vast numbers of observations about plants and animals in all parts of the world, the question was again brought into violent controversy by the English naturalist Charles Darwin (1809–1882). Darwin, Lamarck and Cuvier all agreed that the living species of today are different from their predecessors of ancient times. But according to Cuvier, the predecessors were not the ancestors, whereas Lamarck and Darwin emphasized that "like begets like", and thought therefore that the succession of forms was continuous. That is, they declared the present species to be descendants of earlier ones, with modifications. Yet Darwin and Lamarck did not agree as to how the modifications had come about.

Lamarck's Explanation Lamarck based his explanations on two familiar sets of facts: (1) As everybody knows, the development of an organism is in-

fluenced by its activities or its experiences; muscles grow more if they are used more. (2) Organisms, and especially animals, adjust themselves to their surroundings in the course of their lives—for example, a mature animal is better fitted to supply its needs or protect itself than it was in its younger stages; a child exposed to sunshine will come to have a darkened skin.

From his reflections, Lamarck concluded that "all that has been acquired, begun, or changed in the structure of an individual in the course of its life is preserved in reproduction and transmitted to the new individuals which spring from that which has experienced the change."

This view, widely held, appears quite reasonable. It "explains" the long neck of the giraffe, for example. By stretching to reach the leaves on trees, the ancestors of this species pulled their heads higher and higher above the ground, the argument runs. In any particular generation the stretching may have been very slight, but this little gain was inherited by the offspring. They, in turn, added a little to their height in the same manner. And this process, continuing generation after generation, resulted in the long-necked animal we know today.

This theory can also explain the webbed feet of water birds. A young bird thrown into the water would naturally spread its toes as far as possible to expose the maximum surface for paddling. As the animal continued to stretch its toes apart, the skin between them would gradually spread, resulting after many generations in the webbed foot of the duck or goose.

Lamarck's views appeal to many as common sense. "It stands to reason" that the gains which are made in the course of a generation should benefit the following generation. The analogy from society is impressive. Those who are industrious and thrifty and accumulate more than their neighbors naturally "pass on" more to their children; the latter inherit more. A good home gives children a good start. And they in turn, when they grow up, provide better homes for their children. Communities that have good schools, for example, progress more rapidly than those without schools or with poor schools. Well-nourished plants produce larger seeds, and larger seeds grow into better plants, which in turn produce larger seeds. It all "stands to reason." But what are the facts?

Objections to Lamarck's Explanation We may grant that his experience and activities modify the individual in the course of his development, or that the new species appear to be as well adapted to their surroundings as their ancestors probably were. Lamarck's argument is nevertheless far from conclusive, for in it is concealed an *assumption* which may turn out to be unwarranted. *Are the effects of experience or activities actually transmitted to the offspring?* Is blindness resulting from injury to an eye reproduced in one's children? Is the effect of a broken leg or of practice on a piano inherited? The sons of blacksmiths may have better muscles than the sons of bookkeepers,

on the average. But is that because they have inherited the effects of their father's activities? Or is it, perhaps, because they have inherited the kind of constitution that easily develops large muscles? Are "acquired characters" transmitted? That is not a matter of opinion, but something to be established through repeated observations.

Darwin's Explanation[1] The theory of the modification of species in the course of descent that is associated with the name of Darwin was also formulated independently by Alfred Russel Wallace (1823–1913) and by Herbert Spencer (1820–1903). This theory, like that of Lamarck, is intended to explain (1) how new life forms or species appear in the course of ages and (2) how plants and animals come to be so well adapted to their surroundings.

Darwin's theory rests on two main sets of facts: (1) the fact of variation, that no two individuals are exactly alike; (2) the fact that more individuals (eggs, seeds, spores, and so on) are born than can reach maturity and reproduce themselves. The facts are clear and generally recognized. There is a great deal of variation among individuals. In nature every species does produce new eggs or seeds entirely out of proportion to the number of individuals that could find standing room, to say nothing of food. The resulting "pressure of population" leads to what has been called the *struggle for existence.*

Now every individual dies in the end. For each individual it is a matter of chance whether he does sooner or later. The net result, according to Darwin, is that the destruction of so many plants and animals leaves those to survive and reproduce that are best adapted. In other words, the outcome of the "struggle" is a survival of the fittest.

Natural Selection Darwin compared this natural process to the artificial selection carried on by the plant or animal breeder. He frankly used the expression *natural selection* as a figure of speech, as a quick way to describe just what our common sense would lead us to expect. Darwin did not intend to say that "nature picks out what she wants to preserve", or that "nature favors" one group at the expense of another. He attempted merely to explain how the adaptations of species come about, by emphasizing the general fact, which is easily observed, that members of a family differ from one another in ways that fit some of them to the special conditions of living better than others.

Objections to the Selection Theory "Struggle for existence" is a fair description of the activities of plants and animals. And much of the outcome is "selective" in the sense that individual differences often mean advantage or disadvantage. Darwin's theory is nevertheless not a satisfactory explanation of how new species have arisen in the course of descent.

Along with the unquestionable facts, this theory makes use of two sets of assumptions. First, it assumes that the differences among individuals are all

[1]See No. 3, p. 470.

Three Explanations for Earth's Changing Population

CUVIER	LAMARCK	DARWIN
Agreed that the Species Living Today are Different from Those of the Past		
Each particular species was created by itself, and is unrelated to any of its predecessors	Each species living today is a descendant of related, but different ancestors	
	New species arose as the effects of use and disuse accumulated and brought about changes in form and function related to the environment	Each species arose as the environment eliminated the least adapted individuals among the variations, and as the adaptations accumulated into progressively more suited forms
DOUBTS ABOUT THE THREE EXPLANATIONS		
Are fossils of ancient species distributed at random, or do they show any systematic resemblance to their predecessors?	Is there anything to show that the effects of use and disuse are inherited?	Do individuals transmit to their offspring the advantages which enable them to survive? Do such advantages accumulate in succeeding generations? Is the destruction or survival of particular individuals, in the struggle for existence, generally due to heritable characteristics?

inherited. At least, Darwin did not distinguish clearly between those characteristics that are inherited and those that are not. As in the case of Lamarck's assumption, this is not a matter of opinion; and the facts in the case were not known in Darwin's time.

The second assumption is that the destruction of living things is in most cases selective. That is, that individuals generally die because of some heritable disadvantage, as compared with those who survive in the same circumstances. There are about every plant and animal multitudes of details that distinguish it from closely related species but that can have no conceivable bearing upon survival. Moreover, vast numbers of individuals are destroyed indiscriminately by floods, fires, general drought, and so on, with only a few survivors remaining, largely through chance.

Darwin's theory may explain the extinction of some strains and the survival of others; but it has no suggestion as to how new characters arose in the first place. If we grant that variations in degree of fitness influence the survival of types, we have remaining the question of *origin*: How do new characteristics originate? Darwin was aware of this difficulty, as appears in his book *The Origin of Species:*

> Several writers have misapprehended or objected to the term Natural Selection. Some have even imagined that natural selection *induces variability*, whereas it implies *only the preservation of such variations as arise* and are beneficial to the being under its conditions of life. No one objects to agriculturists speaking of the potent effects of man's selection; and in this case the individual differences given by nature, which man for some object selects, *must of necessity first occur.* Others have objected that the term selection implies conscious choice in the animals which become modified; and it has even been urged that, as plants have no volition, natural selection is not applicable to them! In the literal sense of the word, no doubt, natural selection is a false term; but who ever objected to chemists speaking of the elective affinities of the various elements?—and yet an acid cannot strictly be said to elect the base with which it in preference combines. It has been said that I speak of natural selection as an active power or Deity; but who objects to an author speaking of the attraction of gravity as ruling the movements of the planets? Every one knows what is meant and is implied by such metaphorical expressions; and they are almost necessary for brevity. So again it is difficult to avoid personifying the word Nature; but I mean by Nature, only the aggregate action and product of many natural laws, and by laws the sequence of events as ascertained by us. With a little familiarity such superficial objections will be forgotten.[1]

The difficulty that all these explanations have in common seems to come from trying to reconcile two unquestionable facts: (1) Like produces like, and (2) Species inhabiting the earth today are different from the species that lived in the past.

[1]The italics are ours, not Darwin's.

Before we can decide whether today's plants and animals are descendants of ancient species, we must first answer the question *Is it possible for any plants or animals to have offspring that are sufficiently different to make up a new species?*

It was many years after the death of Darwin before students of heredity had accumulated enough knowledge to answer this question helpfully.

In Brief

Fossils furnish our most direct evidence about early forms of life.

The fossil record includes entire organisms, skeletons, shells, petrifactions, casts and molds.

Similarities in the structure and life histories of living organisms suggest relatedness; the greater the similarities, the less remote we assume the common ancestry to have been.

Corresponding parts of different organisms built on substantially the same plan are said to be homologous. The presence of homologous parts is taken to indicate relatedness.

Unlike parts of different organisms which carry on similar functions are said to be analogous.

Similarities found between the early stages of development in different species are taken to indicate relatedness.

The presence of certain useless structures within living things is difficult to explain unless we assume that all plants and animals are related through common ancestry.

The uniqueness of life in isolated regions, as contrasted with similarities of life in adjoining regions, can be most satisfactorily explained by assuming that existing species are derived from ancient forms.

The accumulating evidence that plant and animal species populating the earth have changed in time brought two different types of answers: (1) Special creation must have taken place again and again, or new species arose spontaneously again and again. (2) Life has been continuous, but species have become different from their ancestors.

The origin of species cannot be known directly. Either we depend for the answer upon acceptable authority, or we build up the most reasonable hypothesis from actual facts.

Both the theory of natural selection and the theory of transmission of acquired traits are intended to explain (1) the procession of changing plants and animals and (2) the fact that each species is so remarkably well adapted to live in its own special surroundings.

There is no conclusive evidence that modifications arising in an individual's lifetime are transmitted to the offspring.

The theory that species originated through natural selection rests on the *facts* (1) more individuals are produced in each species than can possibly mature and reproduce, and (2) individuals in a species vary among themselves. The theory rests upon the *suppositions* (1) in the "struggle for existence" which ensues from the pressure of population only the "fittest" survive, and (2) the survivors transmit their advantageous characteristics to their offspring.

The theory of natural selection (1) overlooks destructive conditions that are in no sense "selective", (2) disregards the apparent modifications that are not adaptive, and (3) fails to distinguish clearly between variations that are inherited and those that are not.

EXPLORATIONS AND PROJECTS

1 To make a collection of fossils, visit exposed beds of sedimentary rock; split open pieces of limestone or shale, or concretions found in coal or shale deposits, in search of imprints or remains of living things which may be considered as fossils. Identify and label specimens, recording place where found, date, kind of rock in which found, name of fossil, and the geological era or period in which it probably was formed.

2 To become acquainted with life forms characteristic of Paleozoic, Mesozoic, and Cenozoic times, visit a natural-history museum and study the types of life dominant in each era.

3 To estimate the reproductive possibilities in a single plant, collect the seedstalk and count the number of seeds. Select a plant which easily becomes a weed pest, such as dock or ragweed, or a plant commonly raised for food, such as corn or wheat or radish. Estimate how many plants could be produced in three or four seasons if each seed grew and each successive plant produced the same number of seeds.

QUESTIONS

1 Why do not all observers of the same facts come to the same conclusions?

2 What assumptions do you prefer to make as a basis for interpreting the past history of the world? Why do you select these assumptions rather than others?

3 What are fossils? Where do we find them? In what different ways are they preserved?

4 If we accept fossils as representing past life upon the earth, what do the actual fossils and their distribution suggest about the history of life on the earth? What changes do they suggest in the earth itself?

5 What likenesses and differences do we find among the various mammals? among all vertebrates?

6 How do the similarities found among the vertebrates in the early stages compare with those found in adult stages?

7 What theories can explain the presence of useless structures within the bodies of living things? Which explanations agree best with established facts and most widely accepted assumptions?

8 How can we account for the fact that forms living today are different from their predecessors?

9 How did Lamarck explain the origin of new species? What support is there for his explanation? What are its limitations?

10 How did Darwin explain the origin of new species? Upon what observable facts was his explanation based? What support is there for his explanation? What are its limitations?

1. What makes living things resemble their parents?
2. Why are not all the offspring of the same parents alike?
3. Why do individuals of the same species differ from each other?
4. Is inheritance due to something in the blood?
5. Does one parent have more influence on inheritance than the other?
6. How are new breeds of plants or animals produced?
7. Are the effects of experience, training or injury passed on to the new generation?
8. How can we tell whether a certain trait is due to outside influence or to something that is inborn?
9. Are mental qualities inherited, as well as physical?
10. Can anything be done to counteract heredity?

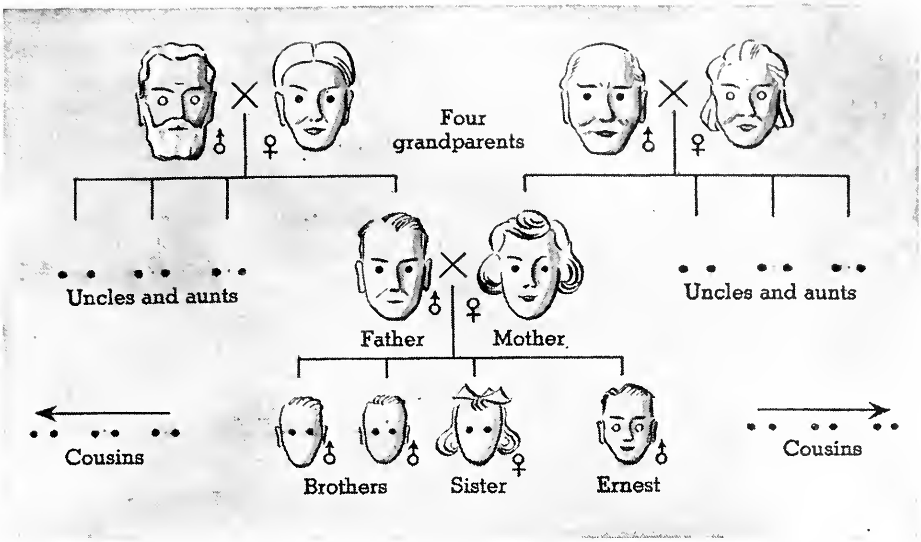
We are so familiar with resemblances between parents and offspring that they somehow seem "natural". But differences are also natural. They are often obscured by the fact that in common species each individual has two parents. For the individual, resembling both parents, seems to us somehow "between" the two. Yet there are always characteristics that we cannot trace to either parent or to other ancestors. Moreover, in the course of an individual's growth he is being modified continuously by the surroundings—nutrition, temperature, light, chemical factors, and so on. In human beings, as well as in other species, experience and training, injury and disease—various *conditionings*—all produce effects. Habits and skills, attitudes and sentiments, likes and dislikes, become changed. Even under uniform conditions there appear to be differences.

What causes these differences? For that matter, what causes the resemblances? What happens when varieties are crossed? Are mental qualities inherited in the same way as physical characters?

How Can We Trace Inheritance through Successive Generations?

Race Experience People everywhere seem to believe that "heredity always runs in families" (see illustration opposite). Many ancient peoples had strict rules regulating marriage. Some forbade the marriage of cousins and of even more remote relatives. Some had no such restrictions. In some societies brother-sister marriages were accepted as proper, although these are looked upon with abhorrence by most peoples today. The reasons for the various rules rest on what people assumed or believed about heredity or about "race".

Breeders of race horses train the animals for swiftness, and then try to



WHAT RUNS IN FAMILIES?

Ernest has blue eyes, although both his parents and his sister and his brothers have dark eyes — like his cousins and his uncles and his aunts. Some say he gets his blue eyes from his grandmother Brown, but others say he gets them from his grandfather Green. How can we tell?

improve the stock by breeding from the swiftest. And the modern race horse is indeed a great improvement upon the progenitor of only a few decades back. Do the training and racing of horses influence the performance of their offspring? Or does the performance reveal the possibilities of the stock? Or how is the stock improved?

What people have believed about the connection between parent qualities and offspring qualities has influenced their treatment of pregnant mothers. There has been a widespread belief, for example, that if a pregnant female experienced a violent shock or a violent pleasurable emotion, the unborn child would somehow show the effects. Birthmarks, deformities, and even special talents were often ascribed to such experience. Many animal-breeders tried to influence the coloring or markings of their calves or lambs by exposing the mothers to appropriate scenery. Similarly, many human mothers today hope to ensure beautiful features for their unborn babies by gazing on the pictures of beautiful women or men.

People generally think of "heredity" as a strange, mysterious force, which may or may not strike, like lightning or good luck or a pestilence. It is only in modern times that systematic research has attempted to solve the larger problems of heredity. For example, how can we *measure* degrees of resemblance among individuals? *How far* can selection be carried? Can a stable,

or constant, species be established with *no variation* among individuals? Can *standard* surroundings be established to prevent variation? What *connection* is there between the characteristics of individuals and the structure of eggs and sperms?

Analyzing the Problem The first systematic experiments in heredity of which we have any record were those of Gregor Mendel (1822–1884), an Austrian monk. Mendel had long puzzled over the great amount of variation among his garden peas. There were tall plants and short ones, plants with white flowers and plants with colored flowers, with yellow seeds and with green seeds, with smooth seeds and with wrinkled seeds. He noticed further that a given plant might have *any combination* of the single members of these pairs. Thus a hairy plant might be tall, or it might be short; a tall plant might have white flowers or pink flowers; it might have yellow seeds or green seeds; and so on. All in all, Mendel studied seven different pairs of contrasting characteristics in the pea plants (see table, below).

Mendel's Experiments with Garden Peas[1]

CONTRASTING CHARACTERS IN	THE TWO PARENTS	CHARACTER IN OFFSPRING
1. Seed coat	Smooth × wrinkled	All smooth
2. Cotyledon color	Yellow × green	All yellow
3. Height of stem 6–7 ft or 1–2 ft	Tall × dwarf	All tall
4. Pods—inflated or sunken between seeds	Hard × soft	All hard
5. Unripe pod, color	Yellow × green	All green
6. Position of flower	Axial × terminal	All axial
7. Seed-coat color	White × colored (gray or brown)	All colored

In one plot Mendel placed pollen from a tall plant upon the stigma of a short, and vice versa. In another he crossed smooth-seeded and wrinkled-seeded plants, in both directions. In this way Mendel made reciprocal crosses with hundreds of pairs of plants having contrasting characters.

Mendel's First Discovery[2] When Mendel crossed green-seed and yellow-seed plants, the resulting seeds developed into plants yielding only yellow seeds. When he crossed tall and dwarf plants, the offspring were all tall. With each of his seven pairs of characters, Mendel found that the offspring resembled *one of the parents completely*. Thus the offspring of colored-flower and white-flower strains all had colored flowers. If these results are surprising, it is because most of us have failed to notice that the resemblance of children to their parents consists not only in having characters lying

[1]Breeders long tried, without success, to find out how a hybrid "variety" acts in heredity. Mendel crossed plants that differed from each other in a particular character—tallness, for example, or color. In thousands of crossings between individuals with contrasting characters, he found that all the hybrids in each series were alike, whether the quality in question had been carried by the male parent or the female parent. [2]See Nos. 1 and 2, p. 503.

Mendel anticipated by thirty-five years the practical establishment of the art of breeding new species of plants and animals, kinds that had never existed in nature. It is commonly assumed that an organism transmits its distinctiveness entirely, or else not at all. This means that a Jersey cow, for example, transmits to her offspring all her "jerseyness" or that a cherry transmits all its "burbankness"—or none. Mendel analyzed the "character" of a strain into its many separate qualities. His basic scientific and practical contribution was the working out experimentally of a method for ascertaining the essential facts as to just what is inherited — just what particular characteristics appear in successive generations, what ones fail to appear, what ones reappear later

Historical Pictures Service

GREGOR MENDEL (1822–1884)

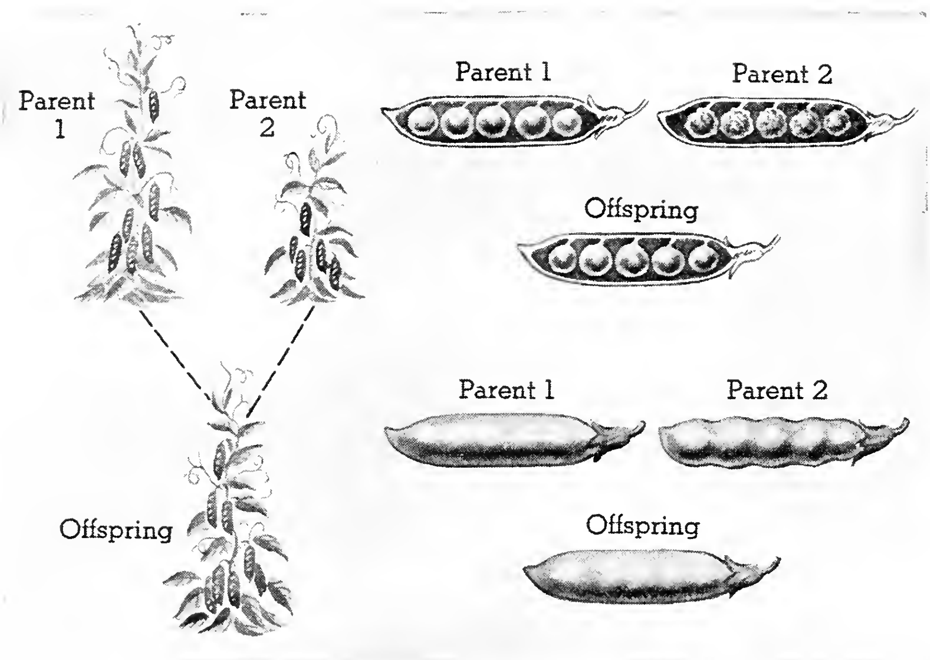
between the corresponding characters of the parents, but partly in having some characters just like those of the mother and other characters just like those of the father (see illustration, p. 476).

The results which Mendel obtained he generalized as the law of *dominance.* His idea was that where the two "factors" causing the contrasting characters meet in an individual, one of them dominates over, or masks, the other one, which Mendel called the *recessive.* The recessive is not destroyed, as we shall see. Of course it is impossible to tell in advance which of two characters in a contrasting pair will be dominant and which will be recessive. The cross has to be tried out (see the tables on pages 480 and 481).

The Law of Segregation[1] The yellow seeds of a hybrid plant are not distinguishable from the yellow seeds of the *pure* yellow-seeded parent—just as you cannot tell whether a brown-eyed person has two brown-eyed parents or only one. With plants grown from hybrid yellow seeds, Mendel carried out three classes of cross-pollenation (see illustration, p. 477): (1) He crossed hybrids with plants of the parent (pure) yellow-seeded variety. (2) He crossed hybrids with plants of the parent (pure) green-seeded variety. (3) He crossed yellow-seeded hybrids with yellow-seeded hybrids.

From these experiments, which have now been made with hundreds of species of plants and animals, it is seen that the *hybrid does not reproduce itself in offspring having uniform characteristics.* Some of the offspring resemble the grandmother's type, and some the grandfather's type. This general fact of "splitting" is called the law of *segregation.* It agrees with the past experience

[1]See No. 3, p. 503.



MENDEL'S FIRST SURPRISE

From our common experience we expect offspring to resemble both parents. When Mendel crossed a pure breed of tall plant with a pure breed of dwarf, all the offspring were tall. When he crossed a pure smooth-seed variety with a wrinkled-seed variety, all the offspring had smooth seeds. The hybrid of hard-pod and soft-pod varieties all had hard pods. The results were the same whichever parent had the special trait

of breeders, who consistently failed to establish new varieties even where they constantly mated hybrids with similar hybrids.

Inbreeding of the hybrids yields two kinds of offspring: (1) those with the dominant character and (2) those with the recessive character (see illustration opposite). That is, the two original qualities—green and yellow seeds, for example—reappear. The progeny of the hybrids break up into two types, resembling the two ancestral types. These two types of offspring segregate in the proportion of three dominants to one recessive (3 : 1). Inbreeding in the next generation leads to further segregation—a fact which had always confused hybridizers in the past. But here a new fact appears: *all the recessive green* plants in the second hybrid generation *breed true*, and also *some* of the dominant yellow.

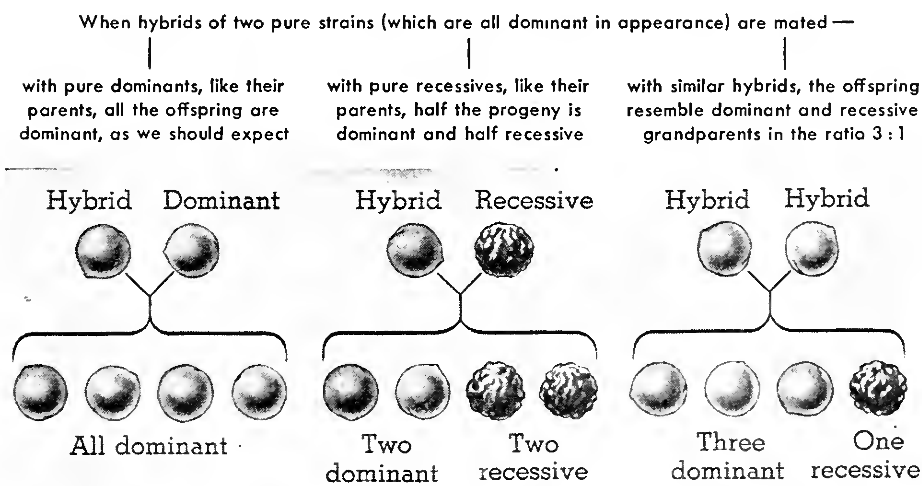
Purifying the Mixture The recessives (greens) breed true in every succeeding generation. This is in spite of the fact that they were derived from yellow (hybrid) parents. Such "extracted" recessives are considered "pure," for *they always breed true.*

In each generation, then, the descendants of hybrids will behave in three possible ways with respect to a particular characteristic: (1) the recessives will remain pure, or capable of reproducing the recessive trait; (2) one out of every three dominants will turn out to be a pure dominant; (3) two out of the three seemingly dominant plants will behave like hybrids and split up again when they reproduce.

Combinations of Characters[1] We know that *every organism consists of not one, but many characters.* Mendel also experimented on the results of crossing peas *with different combinations of characters.* Two plants, for example, differ not only as to the color of the seed but also as to tallness. What happens when they are crossed? Mendel crossed tall green-seeded plants with short yellow-seeded ones. All the next generation were dominant for size (tall), and dominant for seed-color (yellow). The hybrids resembled one parent altogether in one character, and the other parent entirely in the other character (see illustration, p. 478). In the following generation the offspring of such hybrids appeared in four types: tall-yellow, short-yellow, tall-green, short-green. That is, there was "segregation" for *each* pair of characters.

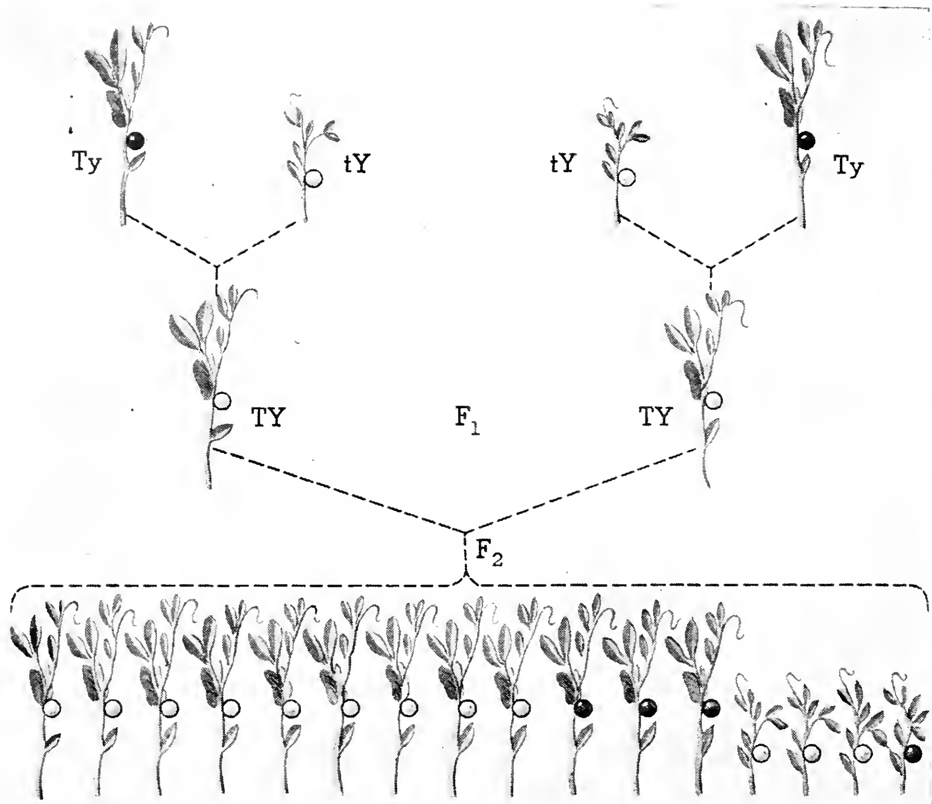
Experiments of this kind have since been repeated by the thousand. From them we conclude that each pair of alternative characters behaves according to the first two laws (*dominance* and *segregation*), regardless of the other characters present. This general fact is called the *law of independent assortment,* or the law of unit "characters" (see illustration, p. 479).

This principle of independent characters may help us understand how



HYBRIDS IN THE SECOND GENERATION

[1]See No. 4, p. 503.



INHERITANCE OF TWO OR MORE CHARACTERS

Mendel crossed a strain that had one character dominant with one that had a different character dominant — say, a tall green-seeded plant with a dwarf yellow-seeded one. All the offspring had both dominant characters. When the hybrids, F_1, were mated, segregation of the dominant and recessive characters in the ratio of 3 : 1 took place in the following generation, F_2, independently for each pair of contrasting characters

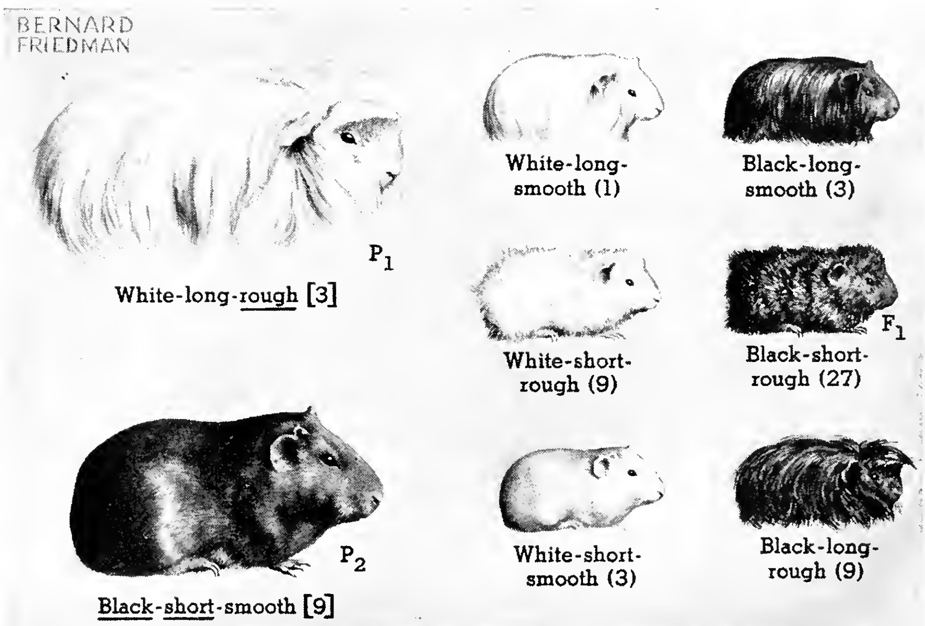
there can be such great diversity among individuals of any given species, or even among the brothers and sisters of any family. The greater the number of characters, the greater is the possible number of combinations, and the smaller is the chance that any given combination will occur again.

These three laws of heredity—*dominance*, *segregation*, and *independent assortment*—are known as Mendelian laws, or principles, because they were first discovered by Gregor Mendel.

The Rediscovery of Mendel Gregor Mendel read a paper on the results of his experiments in 1865, and the following year published the paper in the journal of the local scientific society. There it remained in dead storage to the end of the century. For there is no indication that any of the scientists

or practical breeders discovered this work or noted its significance. Others were also carrying on experiments, however. By the end of the century three botanists, working independently and each one experimenting with different material, were arriving at the same conclusions Mendel had reached. They discovered Mendel's old report and called attention to it. These three botanists were the Hollander Hugo de Vries, the Austrian Erich Tschermack, and the German Karl Correns.

While these investigations were going on, an American breeder was making the same discoveries in an effort to develop a wheat especially suitable for growing in the Northwest. In the region about Pullman, Washington, the farmers had for years tried out many varieties of wheat in order to decide which was the most profitable to grow. They found only the Little Club variety at all satisfactory. The straw was strong enough to withstand the summer storms, and the head remained closed after the grain was ripe, thus preventing loss before harvesting. But when Little Club was planted in the



After experiments by W. E. Castle

INDEPENDENT ASSORTMENT OF CHARACTERS

In guinea-pigs pigmentation is dominant, as are shortness of hair and roughness of coat. When two pure-bred individuals like P_1 and P_2 are mated, all the hybrids will be dark, short-haired, and rough-coated, like F_1. If such hybrids are now mated in sufficient numbers, the next generation will yield every possible combination of the three sets of characters, including the "pure" grandparent types, in the proportions indicated by the numbers in brackets. And for each pair of characters there will be three dominants to one recessive

NAME OF PLANT	DOMINANT CHARACTER	RECESSIVE CHARACTER
Wheat	Late ripening Susceptibility to rust Beardless	Early ripening Immunity to rust Bearded
Barley	Beardless	Bearded
Maize	Round, starchy kernel Yellow grain Purple grain	Wrinkled, sugary kernel White grain Yellow grain
Garden pea	Seeds free in pods Green foliage	Seeds clinging White-spotted foliage
Garden bean	Yellow seed Tallness Round pod Blunt leaf tip	Green seed Dwarf Flattened pod Sharp leaf tip
Tomato	Two-celled fruit	Many-celled fruit
Plum	Red, purple, black fruit Purple flower	Yellow fruit White flower
Potato	Purple in tuber Shallow "eyes" in tuber	White in tuber Deep "eyes" in tuber
Cotton	Colored lint	White lint
Stock Sweet pea Jimson weed	Colored flower Colored flower Colored flower	White flower White flower White flower
Sunflower	Branched stem	Unbranched stem
Nettle	Saw-edge leaves	Smooth-margin leaves

fall, it would be frozen during severe winters—once every three or four years. Although the farmers could get better crops by planting in the fall, they could not afford to lose every third or fourth planting. The problem was, therefore, to combine the good stem and head qualities of Little Club with the frost-resisting qualities of some other variety.

W. J. Spillman (1869–1931), agriculturist of the experiment station at Pullman, began a series of experiments in crossing, or hybridizing, the Little Club wheat with other varieties. Whichever variety he used as the pollen parent, the same group of characters appeared in the next generation. This agrees with what we have learned as Mendel's law of *dominance*, although Mendel's work and his special terms were not known to breeders or biologists (see page 475). Spillman found also that among the offspring of hybrids, every possible combination of the grandparents' characters occurred. This agrees with Mendel's principle of *segregation*.

NAME OF ANIMAL	DOMINANT CHARACTER	RECESSIVE CHARACTER
Cattle	Hornlessness	Horns
Horse	Trotting	Pacing
Guinea-pig	Colored coat	Albino
	Black or brown coat	Yellow
	Self-colored	White-spotted
	Agouti fur	Nonagouti fur
	Short fur	Angora fur
	Rosetted coat	Smooth coat
Rabbits	Colored coat	Albino
	Agouti fur	Nonagouti fur
	Short fur	Angora fur
Mice	Pigmented coat	White coat
	Normal movements	Waltzing habit
Dogs	High head carriage	Low head carriage
	Trail barking	Trail silently
	Narrow chest	Broad chest
	Narrow head	Broad head
	Long head (in greyhound)	Short head
	Short hair (in some breeds)	Long hair
	Short foot (in German Shepherd)	Long foot
	Black or liver color	Red
Poultry	Rose comb	Single comb
	Short rump	Long tail
	White plumage	Pigmented plumage
	Extra toes	Normal toes
	Feathered shanks	Bare shanks
	Crested head	Uncrested head
	Brown eggs	White eggs
	Broodiness	Nonbroodiness
Salamander	Dark color	Light color
Canary	Crested head	Plain head
Silkworm	Yellow cocoon	White cocoon
Land snail	Plain shell	Banded shell
Pomace flies	Red eyes	White eyes

By growing from the seed of selected individuals in this third generation and by keeping careful and complete records of the results, Spillman succeeded in combining in one variety of wheat three important characteristics—the strong stem, the closed head, and the frost-resisting qualities. Using similar methods, breeders combined three or more characters desired in a plant from as many different varieties of ancestors.

Rules and Exceptions The rediscovery of Mendel's studies and the simultaneous discovery of his principles by several independent investigators aroused widespread interest. Hundreds of students immediately set to work to check on the amazing new "laws" of heredity. Supporting facts were found through experiments on maize, mice, hens, rabbits, silkworms, wheat, various flowering plants, and many other species of animals and plants.

Earlier experience, as well as many experiments since Mendel's time, show that with some pairs of characters there is not complete dominance. In the case of the blue Andalusian fowl, for example, or of the four-o'clock flower there appears to be what Galton called "blended" inheritance. But from further experiments we now understand that these seemingly blended hybrids behave exactly as do Mendel's hybrid dominants, except that the dominant factor does not completely hide the recessive one.

William T. Bateson (1861–1926), a British surgeon and investigator, had stressed the desirability of studying heredity by experimenting with distinct traits that did not merge or blend gradually into others. He quickly recognized the importance of the Mendelian principles and urged further research. He carried on experiments himself, and on the whole his results agreed with Mendel's findings. But Bateson (who, by the way, invented the name *genetics* for "the science of heredity and variation") discovered some curious exceptions to the principle of independent transmission of traits. For example, purple sweet peas having *long* pollen grains were crossed with red-flowered varieties having *round* pollen grains. In the second hybrid generation the segregation did not yield the four possible combinations in the proportion 9 : 3 : 3 : 1 (see illustration, p. 478). Instead the long-pollen and purple came out together, and the round-pollen and red came out together. In other experiments the large petal, or "standard", of the pea-flower appeared to remain associated with color; it always droops in white flowers and is erect in purple ones. That is, there is some connection, or "coupling", between these two characteristics: they are *not* transmitted independently.

Other exceptions appeared in the offspring of two different strains of white-flowered sweet peas. The hybrids have colored flowers, and their progeny in turn segregate into six different color combinations, in addition to some pure whites. Here, again, the proportions did not fit the expectation according to the Mendelian formula. Many scientists began to feel that they had to take a stand for Mendelism or else against Mendelism.

Multiple Factors Although Mendel's work remained so long forgotten, his selection of material was very fortunate since it enabled him to develop his three "laws" in about eight years, with the least amount of confusion. With other material he might have been completely baffled. The mating of red wheat with white wheat, for example, yields a grain of an intermediate color. In the following generation there is a breaking up into a long series of

shades, including the original types. The latter breed true, but the intermediates continue to split up. After breeders had learned to count the number of individuals of each type that appeared in the progeny of hybrids, it was easy to figure out that the color of wheat grain is inherited through the combined effects of two or more "independent factors". This is in contrast to the "single determiner" which Mendel assumed to account for each of the seven pairs of contrasting characters in his garden peas.

Perhaps we can get the idea of "multiple factors" from a more familiar experience, that of variation in stature. In a group of men with an average stature of 67 inches, some of the individuals are, let us say, only 63 inches tall and others, say, 73 inches tall. Variation in stature is "fluctuating" or continuous. We do not think of a special character "seventy-three-inchness" or "sixty-four-inchness", but we do assume that "tallness" or "shortness" is related to the heredity of the individual—that is, to something transmitted from the parents. But the tallness, whatever it may be in a particular individual, is a composite made up of the x inches of the head, let us say, plus the y inches of the trunk plus the z inches of the legs.

Charles B. Davenport (1866–1944), for many years director of the Laboratory for Experimental Evolution of the Carnegie Institution of Washington, suggested that stature is probably inherited as four (or more) independent "factors" (see illustration, p. 484). That is, any segment of "tallness" might be inherited independently of the others, according to the Mendelian formula. Moreover, "long" might be dominant over "short" in one segment and recessive in another. Some such supposition would help to explain the familiar fact that children are sometimes shorter than both parents, sometimes taller than both parents.

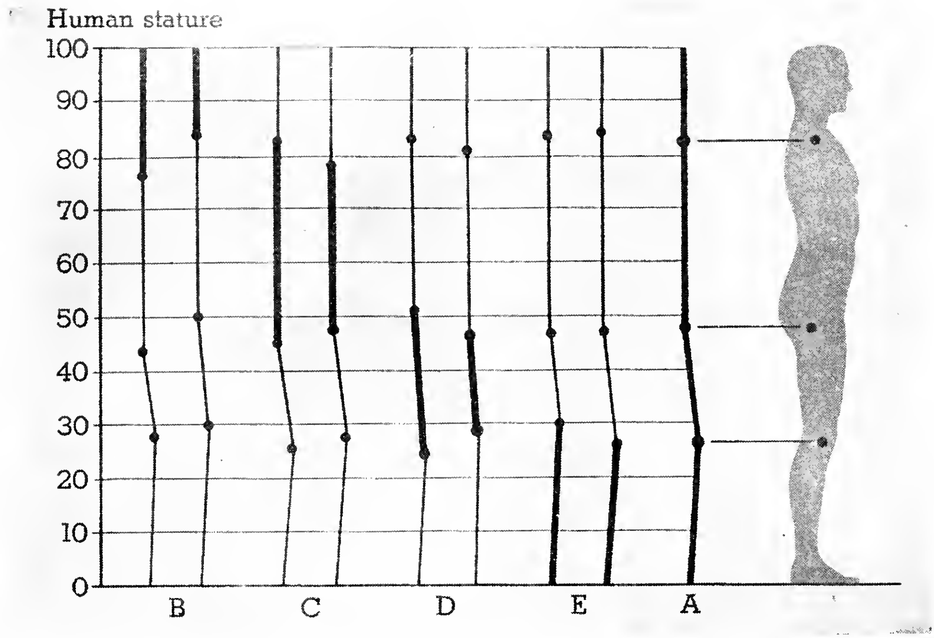
It would also explain why the sons of a thousand tall fathers are taller (on the average) than their contemporaries in general, but not as tall as their own fathers, on the average—an illustration of Galton's "law of regression".

The hundreds of experiments that agreed with Mendel's formulas, as well as those that failed to match these formulas, made people wonder more and more, Just *how* are the characteristics of plants and animals transmitted?

What Is the Connection between Heredity and Reproduction?

What Is Inherited? It is common to speak of the inheritance of characters as though something passed from parents to offspring. But a moment's thought will show that nothing is transmitted in the ordinary literal sense.

What we really mean by saying that a plant or animal has inherited certain characters from his parents is that *there is something in the fertilized egg that brings about the development of those characters.* But whatever is in the egg must have come from the gametes, and so, presumably, from the parents.

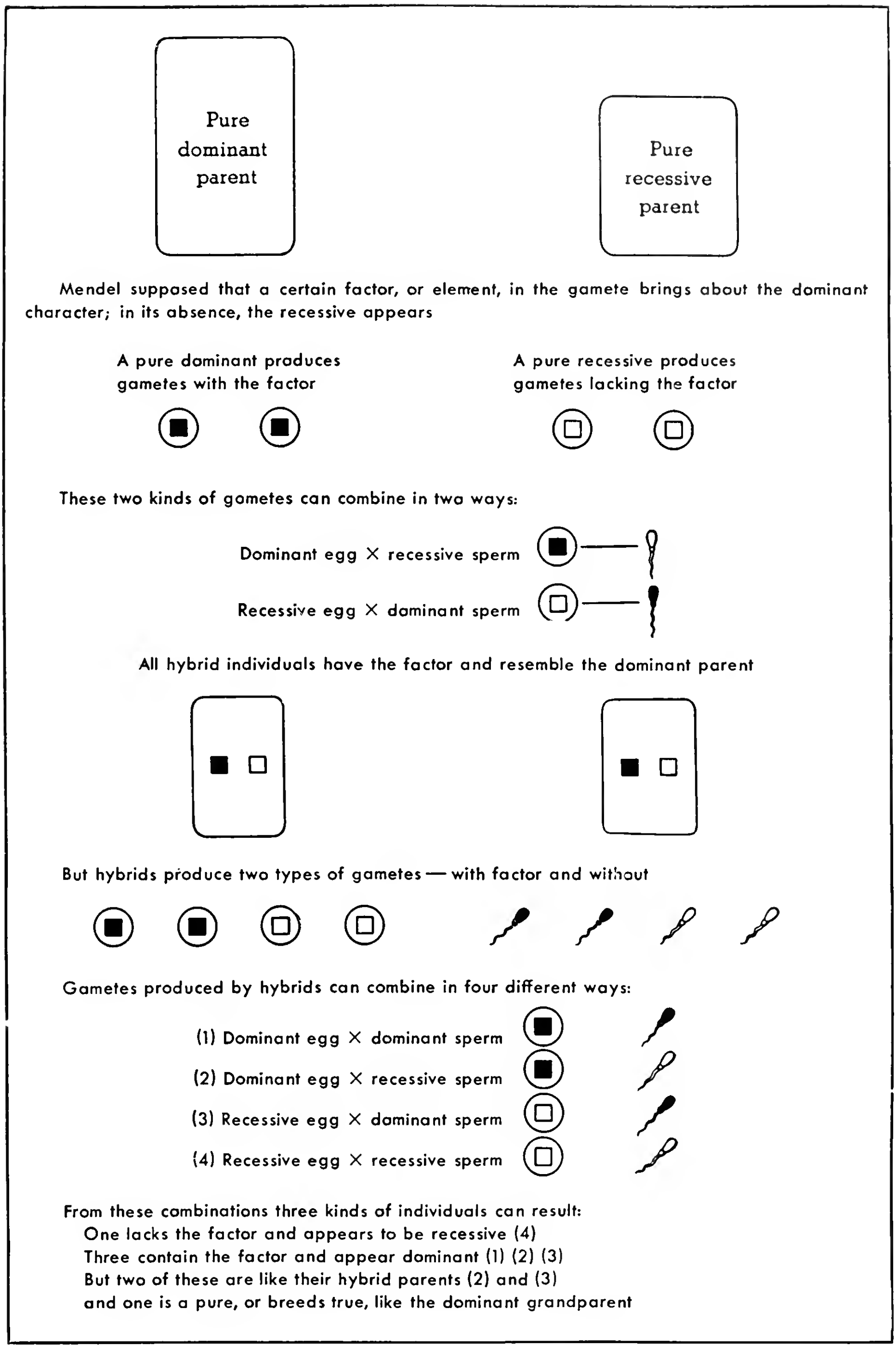


MULTIPLE FACTORS IN INHERITANCE

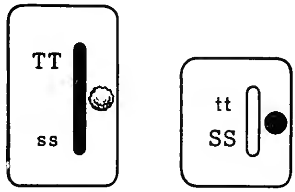
A person's stature is represented, on a percentage scale, as the sum of four segments, the length of each being determined by independently inherited factors. The average proportions of the four segments are shown at A. The extremes for the head-neck segment are shown at B, those for the trunk at C, and so on. One does not inherit six-footedness, or even tallness or shortness, as a simple trait. One inherits several independent factors which, acting together, result in a man's being 5 feet 6 inches or 6 feet 1 inch. (Based on data from C. B. Davenport)

When Mendel made his experiments, little was known about the nucleus of cells, and nothing about the behavior of chromosomes during cell-division. To explain his findings, however, Mendel made certain *suppositions*, or guesses, about what *probably* goes on as eggs and sperms are being formed. And his suppositions turned out to agree in some ways remarkably well with the facts (see illustration opposite).

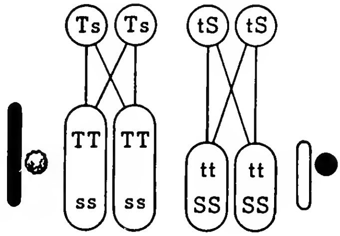
Nuclear Division We have already seen that when germ cells (eggs and sperms) are being formed, the number of chromosomes becomes reduced to half the number present in each body cell. When a sperm cell unites with an egg cell in fertilization, the resulting zygote contains the full number of chromosomes. Half of these came from the male parent and half from the female parent (see illustration, p. 376). If we suppose that the chromosomes bear Mendel's assumed "determiner", the behavior of the chromosomes fits in astonishingly with the facts found by Mendel and other experimenters. This was pointed out by an American biologist, W. S. Sutton. The facts of



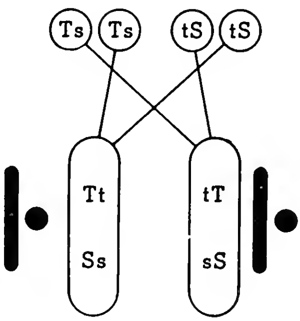
HOW MENDEL EXPLAINED SEGREGATION: THE PRESENCE–AND–ABSENCE THEORY



Individuals of pure breed can produce only one combination of chromosomes in their gametes



If they are not crossed, their gametes can result only in pure individuals, having the same combinations of recessive and dominant traits as the parents



When gametes from two strains combine, the zygote receives chromosomes of different kinds

Pure gametes can combine in two different ways:

Parent type A eggs × B sperms
Parent type B eggs × A sperms

The zygotes have the same chromosome combination in either case, and in all the hybrid progeny each trait is dominant in appearance

When hybrid individuals form germ cells, the parental chromosomes of each pair become separated in the reduction division

Four types of eggs and four types of sperms make sixteen different zygotes possible

Sperms → / Eggs ↓	TS	Ts	tS	ts
TS	TS TS	Ts TS	tS TS	ts TS
Ts	TS Ts	Ts Ts	tS Ts	ts Ts
tS	TS tS	Ts tS	tS tS	ts tS
ts	TS ts	Ts ts	tS ts	ts ts

The segregation agrees perfectly with the results of Mendel's experiments:

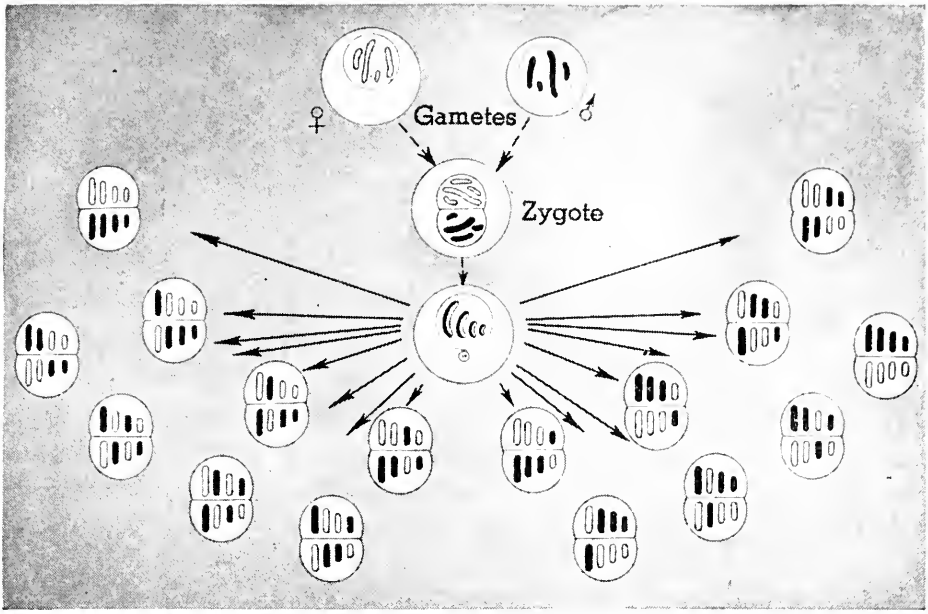
12 tall : 4 not-tall
12 smooth : 4 not-smooth

In appearance, they are

9 TS : 3 Ts : 3 tS : 1 ts

CHROMOSOME BEHAVIOR AND INHERITANCE

In this type of succession, how many individuals resembling a grandparent can transmit both the latter's distinctive traits?



POSSIBLE COMBINATIONS OF CHROMOSOMES

When a zygote is formed, the paternal chromosomes combine with the corresponding maternal chromosomes. When reduction division takes place as gametes are formed, the chromosomes become separated at random. Where there are four pairs of chromosomes, 16 combinations are possible — 2^n, n being the haploid number

reduction division and fertilization agree with the simple formulas based on Mendel's experiments. But the theory that the chromosomes are the determiners raises new problems (see illustration opposite).

Are Chromosomes Determiners? If each inherited character, or trait, were determined by a particular chromosome, the number of chromosomes in the germ cells would strictly limit variation among individuals. The tremendous variation among human beings, for example, would have to be explained by the combination and recombination of twenty-four pairs of chromosomes. Theoretically the number of combinations possible in any species is 2^x, x being the number of pairs of chromosomes. In a species which had, let us say, only three pairs of chromosomes, the number of combinations possible would be 2^3, or 8. In tobacco or in human beings, with twenty-four pairs of chromosomes, the largest possible number of combinations would be 16,770,216. And this number would include thousands of cases in which two individuals were identical except for one or a few details.

We are forced to assume that each chromosome must bear several, or even many, determiners. Indeed, there is so much evidence on this point that for many years students have been speaking not of determiners in the chromo-

somes, but of genes, a term first used by Johannsen. If now we suppose that each chromosome contains several genes, then independent assortment could take place only between characteristics whose genes were in separate chromosomes. That is, two genes or determiners in the same chromosome would always pass from generation to generation together—just as, in fact, the "linked characters" are found to do (see page 482).

Chromosome Numbers in Various Species of Plants and Animals

Potato (*Solanum tuberosum*):	48	Fruitfly (*Drosophila*):	8
Various other species:	24, 36, 60, 72	Housefly:	12
Blackberries and raspberries (*Rubus*):		Grasshopper:	24
various species:	14, 28, 42, 56, 70, 84	Rat:	38
Other varieties:	35, 49	Swine:	38
Plums:	16, 32, 48	Man:	48
Citrus fruit, varieties:	9, 18	Cattle:	60

Chromosomes and Linkage[1] The discovery of linkage as an apparent exception to Mendel's rule of independent assortment of unit characters turned out to be a severe test or "proof" of the theory. As experiments were extended, more and more cases of linkage were discovered: *not all inherited traits sort out independently.* Moreover, these linkages included large numbers of characters, rather than two or three, which at first seemed to be exceptions to Mendel's principle.

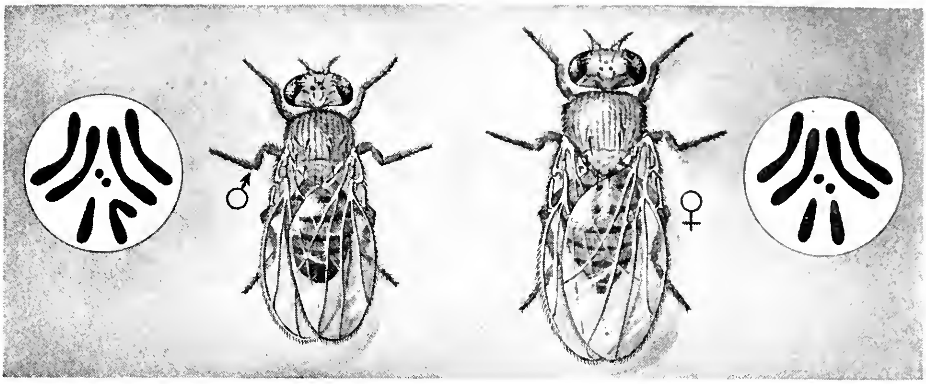
The most telling facts came from experiments with fruit flies of the species *Drosophila melanogaster* (see illustration opposite). Hundreds of trained workers have studied wild forms of this species (see page 491). With the study of linkages it became possible to locate the various determiners, or genes, on each chromosome. One of the earliest linkages studied in the fruit fly was the case of an artificial combination containing two distinct recessive characteristics—a very much reduced wing and a black coloration of the body (see illustration, p. 490).

Other examples were of linkage of this reduced wing with a certain eye-color; another eye-color is usually associated with an ebony body; a vermilion eye is linked with a curious notch on the wing; and so on. The linkages occur in three groups of many characters and a fourth group including only a few characters. These facts strengthen the suspicion (1) that each determiner occurs normally in a particular chromosome, and (2) that the gene is a real something, since the larger chromosomes apparently carry more determiners than the small ones.

But how can we locate a particular gene in a particular chromosome?

Sex-Linked Characters[2] The clue to identifying the chromosomes came from the discovery that in many species the chromosome picture was not

[1]See No. 5, p. 504. [2]See No. 6, p. 505.



After Morgan

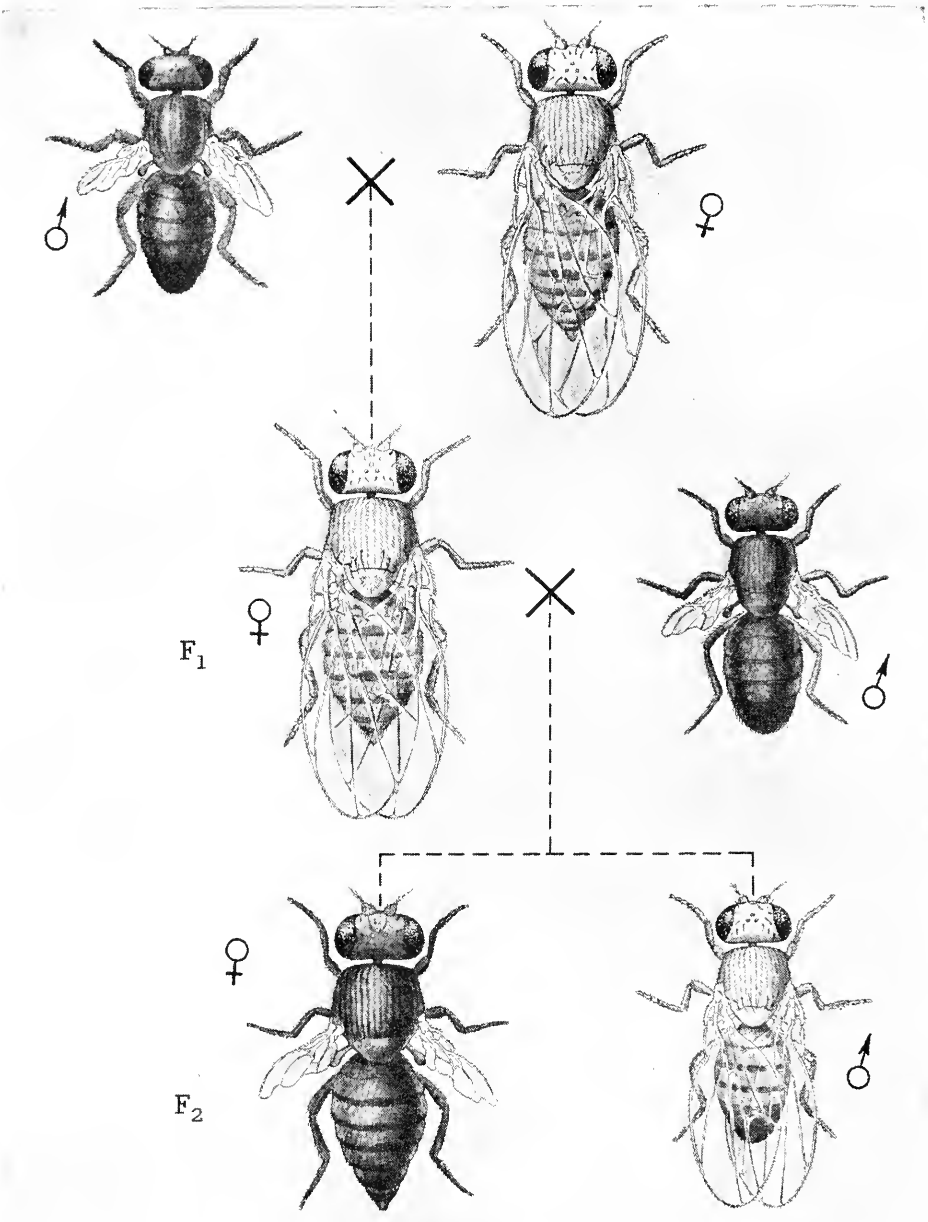
ADULTS AND CHROMOSOMES OF THE MALE AND FEMALE FRUIT-FLY, DROSOPHILA MELANOGASTER

This species has been more thoroughly studied than any other animal, with the possible exception of man himself. Thousands of inheritance experiments have been made on the ordinary traits of the wild forms of the species, and hundreds of mutations have been traced through dozens of generations

the same in males as in females. Although we speak of all the chromosomes as *paired* in body cells, in one of these pairs the two members are not quite matched. In some species these two unmatched chromosomes differ merely in size (see illustration, p. 491). In some species the smaller one may be so far reduced as to be quite absent, or at least invisible. In other species there is a difference in shape (see illustration above). Associated with this inequality is the fact that in some species the sex of the individual is determined by the constitution of the sperm, whereas in other species it is determined by the chromosome character of the egg (see illustration, p. 492).

Now it is well known that among human beings a form of color-blindness in which a person cannot distinguish red and green is seldom found in females. If we suppose that this characteristic results from the presence of a special gene in the sex chromosomes, we can explain the actual distribution of color-blindness. Color-blindness "skips a generation" in inheritance, being transmitted not from fathers to sons, but from grandfathers to grandsons, and only through the daughters (see illustration, p. 493). This is a familiar sex-linked character.

In studies on the fruit fly about two hundred characters have been found to be sex-linked. The genes which determine these characters have been assumed to be in the sex chromosomes, the so-called X-Y pair, shown in the illustration above as a short, straight chromosome and one sharply bent. Then there are two larger linkage groups which have been assigned to genes in the two larger chromosomes. There is a much smaller group of linked characters which have been assigned to the smallest chromosomes.



After Morgan

LINKAGE OF TWO CHARACTERS IN THE FRUIT-FLY

Blackness and short wings in a male mutant are recessive to normal coloration and normal wing. In the second hybrid generation these two characters do not become segregated, but always come out together; as we should expect, "independent assortment" takes place. It is inferred that the determiners lie close together in the same chromosome

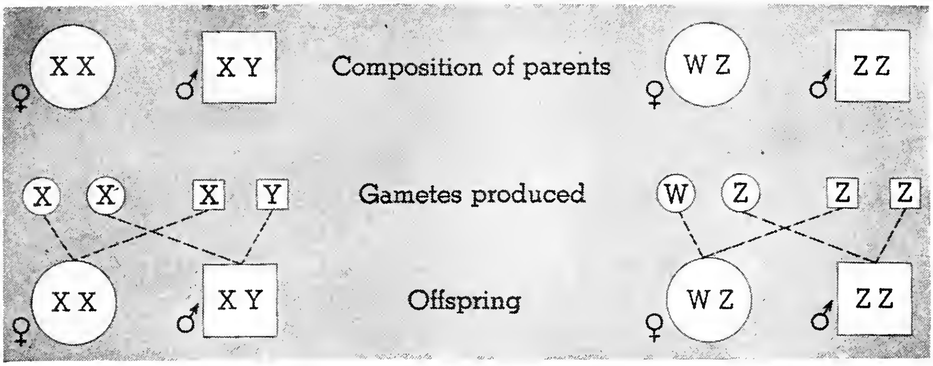
CHROMOSOMES IN MAN

The 24 pairs of chromosomes are shown in order of size. The members of each pair are indistinguishable, except that the smallest, marked X and Y, differ in size in the male. During reduction division, when sperm cells are being formed, the X goes to one sperm and the Y to another. All eggs, however, have the X chromosome. Structural variations which the microscope may reveal among chromosomes of different individuals cannot be related to personal or racial traits

Chromosome Maps We have seen that it was through the idea of *linkage* that Morgan and his fellow workers came to place certain genes together in particular chromosomes—that is, from following up *exceptions* to Mendel's law of independent assortment. Since a chromosome is generally an elongated structure, it seems reasonable to suppose that the genes are probably arranged along the length of the chromosome. Now the question naturally arose, Is there any way of locating particular genes more exactly along any particular chromosome?

This problem was solved by studying the *exceptions to the idea of linkage.* Characters are coupled; but linkage is not 100 per cent consistent. Certain pairs or groups of linked characters become separated in succeeding generations more frequently than others. If we suppose that the genes are arranged in a series, we should expect that those which are close together in a chromosome would seldom become separated, whereas those at opposite ends of a chromosome might become separated more frequently. But what happens in the chromosomes to produce such a break in the chain (see illustration, p. 494)?

The observed fact that parts of chromosomes sometimes break off and cross over to the other member of the pair seems to run parallel with the experimental fact that characters which are usually coupled together in suc-



TWO TYPES OF SEX DETERMINATION

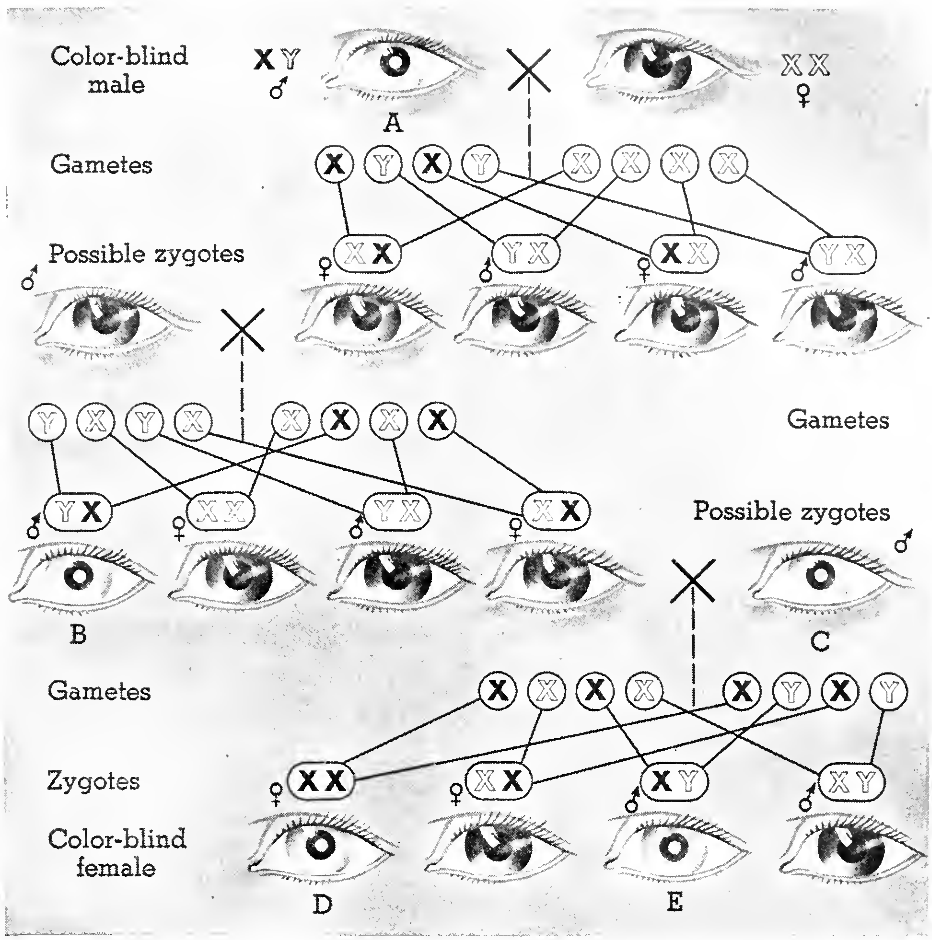
In many species of mammals, insects and plants, all eggs have an X-chromosome, but half the sperm cells have an X-chromosome and half a Y-chromosome. Fertilization by an X-bearing sperm results in a female. In many birds and butterflies the eggs are of two kinds — one with a Z and one with a W chromosome. The combining of two Z-chromosomes results in a male

ceeding generations sometimes become separated. Assuming that there is a real connection between these two sets of facts, Morgan and his associates developed their famous chromosome "map" of *Drosophila*. In this map hundreds of spots on the chromosomes are assigned to the various genes that are supposed to determine particular characteristics. Relative positions of genes are based on the relative consistency with which two or more traits remain linked in successive hybrid generations. Fragmentary chromosome maps on the same plan have been made for various species of plants and animals, including man.

Multiple Factors—Multiple Action After being for centuries the source of endless confusion, superstition, and fruitless speculation, the problems of "heredity" began to clear up almost suddenly when scientists attacked them experimentally around the turn of the century.

We have learned to think of *genes* as particular objects—perhaps particular kinds of molecules—because this idea has helped us analyze (1) the behavior of the chromosomes during cell-division, during the formation of eggs and sperms, and during fertilization, and (2) the distribution of characteristics in particular species of plants and of animals.

We now know pretty definitely that the inheritance of characteristics and the chromosome behavior are closely related. But we have learned also that no one gene does actually bring about a particular characteristic. On the contrary, all the findings point to the probability that (1) each gene, or "determiner", produces a multitude of effects and not merely the one which happens to catch our attention as a basis for experimenting; and (2) each "character"

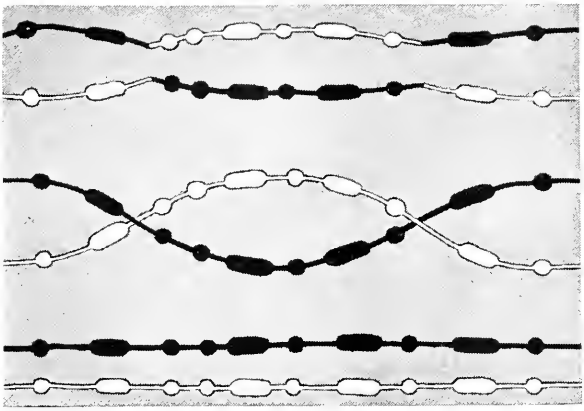


COLOR BLINDNESS LINKED TO MALENESS IN MAN

To understand why color blindness is generally found only in males, we assume that it is determined by a recessive factor in the X-chromosome. If the affected X combines with a normal X, the recessive character does not show. A female would be color-blind only with two affected X-chromosomes — that is, if she were the daughter of a color-blind man and of a normal woman whose father or grandfather was also color-blind

results from the interacting of many elements or factors from several genes being present together, often in separate chromosomes. An interesting example of these ideas is seen in the commercial production of "Silver Fox" furs (see illustration, p. 495).

Two distinct mutations have occurred among the foxes, both producing a black, or silver, fur; and both breed true. The Standard Black, as it is called, originated in Eastern Canada; the Alaskan Black, in Alaska. Both



During conjugation of germ cells, the two members of each pair of chromosomes become intimately intertwined. When they separate again, portions of the two chromosomes seem to have become interchanged. The occasional failure of linkage would seem to be due to the occasional interchange of chromosome segments between the paternal and maternal chromosomes of a particular pair

CROSSING OVER

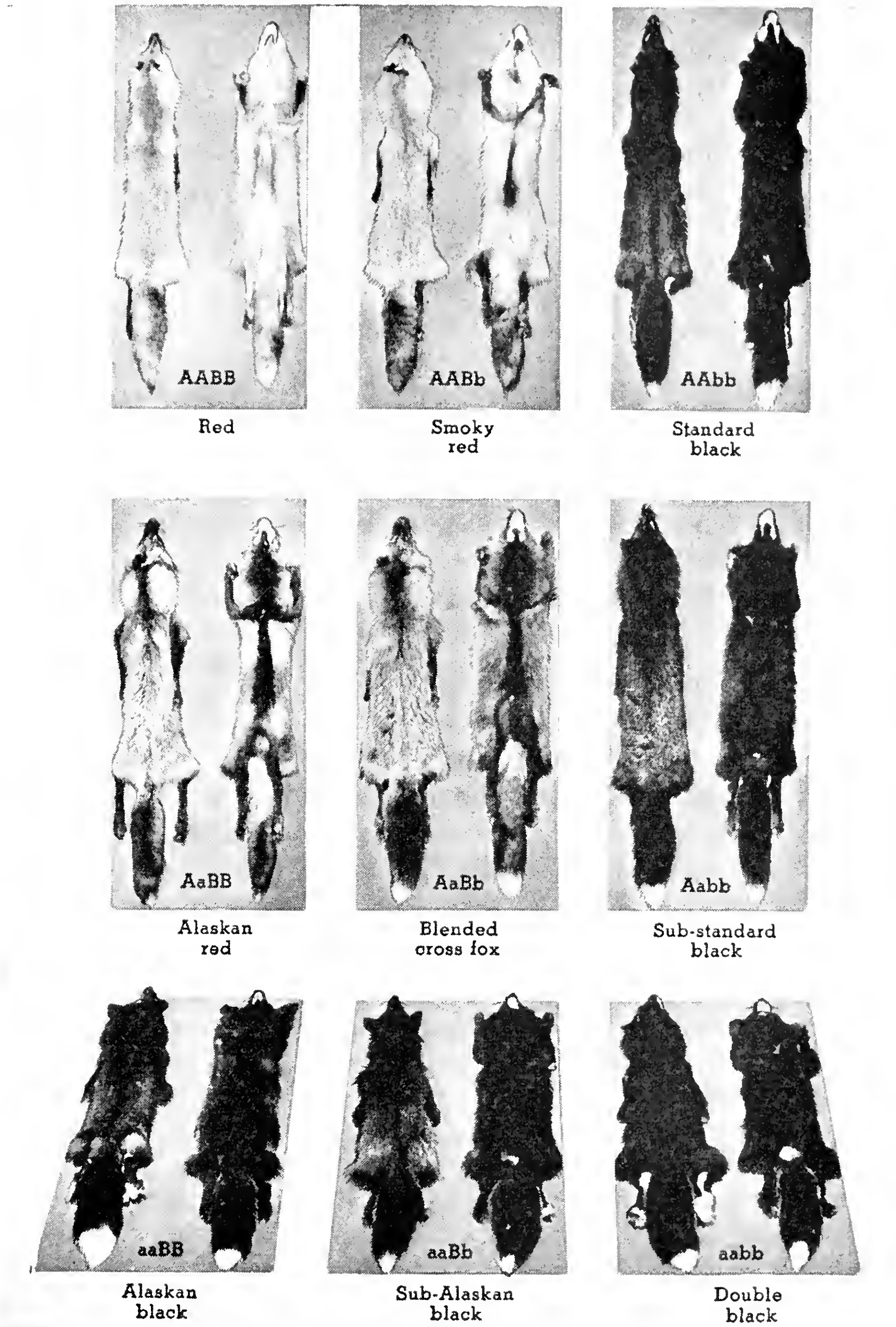
are black, as the photograph shows; yet they are distinct in appearance—and distinct in their hereditary or breeding behavior. When these two types are mated, there appears only the "Blended Crossfox" type. When these hybrids are mated, their offspring divide into nine easily recognized types, which are shown in the picture. That is, the hybrids are heterozygous with respect to some of the genes, or factors, that determine the coat characteristics. This is, of course, what we should expect on a simple Mendelian interpretation. But further study shows that the situation is not simple. Among the offspring of these hybrids 25 per cent, on an average, are of the parental hybrid type, the crossfox; but there are also four *other* "hybrid types" — $12\frac{1}{2}$ per cent of each. And finally, there are four types that are "pure" — two like the black grandparents, as we might expect, and two quite different. These two are the so-called "double black", which is quite new, and the "red" fox — the original wild type.

An analysis of these experiments indicates that there are probably two pairs of genes that account for the facts. The types shown in the four corners of the illustration all breed true; that is, each of the genes in question occurs in a homozygous state — altogether dominant or altogether recessive. This is represented by the symbols **AABB**, **AAbb**, **aaBB**, and **aabb.** We can check this idea by working out (1) the result of inbreeding any of the hybrids; and (2) the result of mating any two of the hybrid types, using the Punnett squares.[1]

Each character of the organism, each part, perhaps even each gene in the chromatin of a cell, influences the whole body. And each part or process is influenced by all the others. The organism continues as a unity.

Our method of study makes it necessary to analyze. We analyze the or-

[1]See No. 4*b*, p. 504.



United States Fish and Wildlife Service

MULTIPLE FACTORS IN THE TRANSMISSION OF COAT COLOR AMONG FOXES

ganism into the many structures we can distinguish and finally into its particular characteristics, or variations. We analyze the chromosome-action, trying to find the smallest possible units, in the hope of explaining very complex processes. But however far we may carry our analysis, the problem of heredity remains the problem of life itself: (1) a living organism builds itself out of foreign materials; (2) it passes through a cycle of change which ends in its death; but (3) it perpetuates its own distinct qualities in the living processes of other objects—the immediate offspring or later descendants.

What Are the Practical Applications of Genetics?

Need for Better Types of Organisms Fanciers, commercial breeders, and seedsmen are constantly looking for interesting novelties, both among their own growths and the world over. Occasionally there appears a "sport", or an exceptional individual, with valuable characteristics (see page 509). Furthermore, breeders of plants and animals have not been content with finding desirable individuals or strains by chance, but have attempted to bring about variations of a kind that are both useful and permanent. But it is only since the beginning of the present century that we have known the biological principles for combining systematically in a race or variety a number of desirable qualities, and avoiding undesirable ones.

Among the most serious of the "undesirable" qualities in domestic plants and animals is susceptibility to disease. The late blight of the potato causes an annual loss of about nine million bushels. In the poultry industry the loss of pullets runs from thirty to forty per cent. It is not possible, as we have seen, to transmit *all* the characters that appear in a hybrid or even in a combination that results from segregation. It is necessary that those *factors* or "*genes*" in the two parental gametes which determine a desired character shall be *either both dominant or both recessive.* If only one of the germ cells is dominant, a particular individual may have the quality in which we are interested, but its offspring will be of two kinds (see illustration, p. 486).

Breeding for Immunity Certain American breeds of good beef cattle that could be handled in great herds on large prairie ranches were susceptible to the destructive Texas fever. The "Brahman" cattle of India were immune to Texas fever. On mating these immune animals with a susceptible variety the immunity appears as *dominant.* Brahman cattle were accordingly imported for crossing with our native cattle. A new variety was established; this combined the beef qualities of the American cattle with the immunity of the Hindu type. In this case, breeding for immunity ceased to be important when we learned to prevent the disease (see page 617). But in other cases this principle has been of great value.

In the case of wheat, immunity to "rust" is recessive. It has nevertheless

been possible to establish strains of wheat that combine immunity to rust with other desirable qualities. For, as we have seen, it is necessary to breed a sufficient number of hybrids only into the next generation in order to get a complete segregation of the various dominant and recessive characters, in all their possible combinations. In a third generation we can begin to select offspring with the desired characteristics in a pure dominant or pure recessive condition. Experiments are under way to develop wheat varieties that can resist more severe winters. Crosses between wheat and rye promise to yield valuable results. Some of the many varieties that appear after the hybrids are inbred have valuable wheat qualities combined with the rye's resistance to cold.

Practical Breeding The failure of their hybrids to breed true was the despair of plant and animal breeders in past centuries. Only a few, like Luther Burbank, were successful. Burbank was patient enough to try out vast numbers of hybrids. And he was keen enough to detect the rare individuals that would probably breed true with regard to the desirable combinations of qualities. With our present knowledge of heredity it becomes possible to produce almost any combination of useful or fancy characteristics that we may desire. This does not mean that *new characters* are produced by these methods. When Burbank produced a "white blackberry" he did not get a plant with a new character, in the biological sense. He combined a plant having pale-yellow berries, of no value as fruit, with one having large, black berries—the Lawton blackberry. From the hybrids he obtained segregating offspring. And from the segregated lines he was able to *fix* the strain that lacked pigment and had other desirable qualities in a "pure" state—that is, had only recessive genes or only dominant ones from *both* parents.

Every year experiment stations and private gardens of seed-producers, nurserymen, and horticulturists offer us "new" flowers, fruits and vegetables. Many of these new varieties are hybrids which cannot breed true. Such plants are propagated by means of cuttings or grafts or by means of bulbs or tubers. The Burbank potato, for example, which originated as a seedling and has been one of the best-known potatoes in this country, has to be propagated by means of the tuber. Seedless varieties of grapes, apples, oranges, and so on, would, of course, be propagated by grafts or cuttings. But all cultivated fruits are propagated vegetatively even when they have seeds. Since they are hybrid, their seedlings would "split up" the *combination* of qualities that is of value.

Novel combinations in annual plants, which have to be grown from seeds every year, present special difficulties. But the breeders are offering more and more varieties of hybrid *seeds* for field and garden. These seeds will grow into plants having the desired combinations of characters. But the seeds of these plants will "throw back" into the numerous ancestral types; that is, they will segregate.

If one wants to continue growing plants with the same qualities, he has to

buy new seeds every year. Hybrid corn is offered that has been built up of more "elementary" types of corn, which in turn were obtained by systematic *in*-breeding. These plants are small and poor in many ways. But the hybrids are vigorous and combine the desired features of several strains. If you plant seeds *for* purple petunias, you will get a handsome growth; but if you plant the seeds *from* purple petunias, you will get half a dozen or more varieties, but very rarely a purple flower.

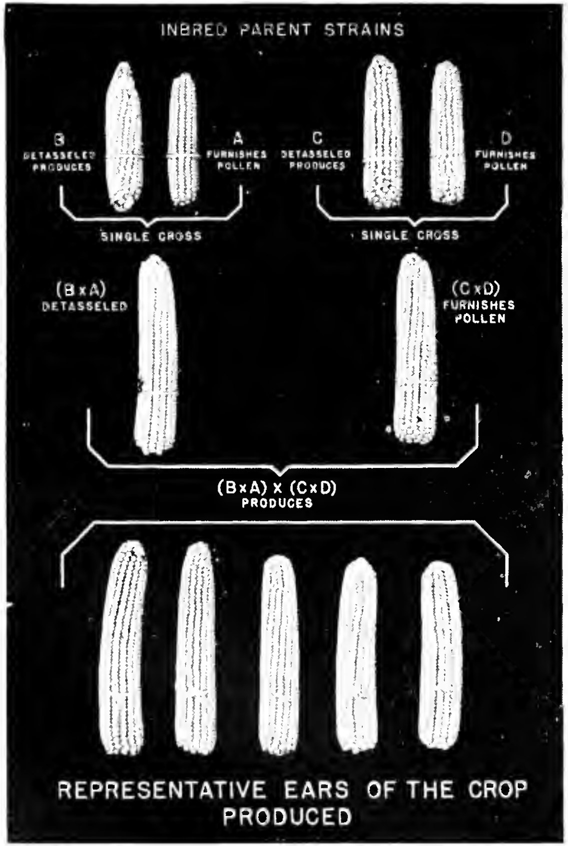
The production of giant blueberries illustrates the range and complexity of problems involved in the creation of new plants. These blueberries are self-sterile. It is therefore necessary to grow them along with another variety to supply the pollen. The plants do not easily form roots on cuttings; this difficulty is met through the use of growth-stimulating substances (see page 257). But we do get the giant blueberries.

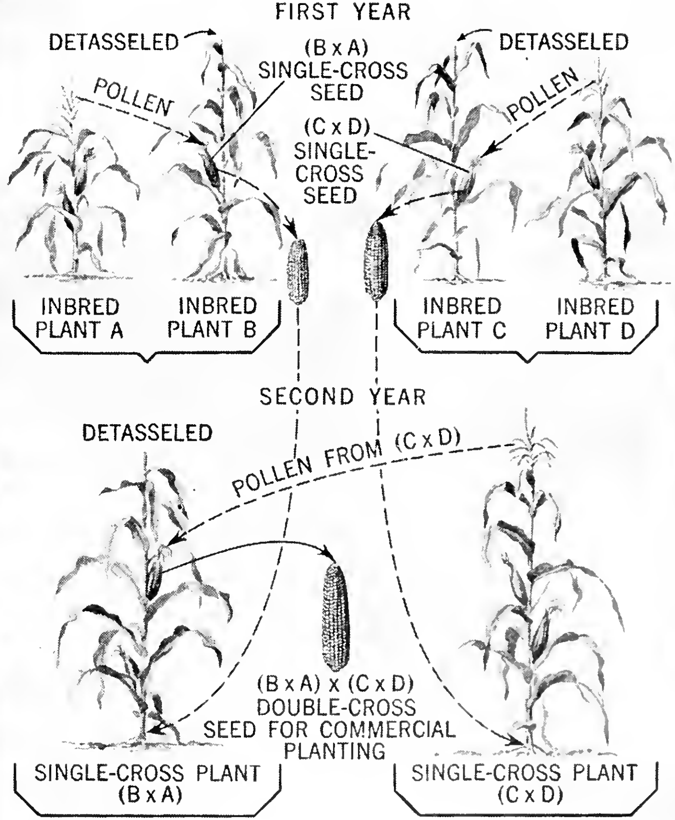
Through modern methods of crossing and testing, those interested in special types of plants are constantly producing new varieties with distinct characteristics—early ripening, long fiber, particular colors and flavors, resistance to heat or drought, resistance to various diseases, and so on.

Problems of Animal Breeding In every species of domestic animal there are many more or less distinct varieties. In fact, two artificial breeds of dogs or horses, for example, may differ more, outwardly, than two distinct species in nature. The breeder's first problem is to find the variety or breed that is of greatest value or most suitable for his particular purposes. The next problem is to get the desirable qualities to repeat themselves generation after generation. Those who have to handle cows or sheep, for example, often find the horns in these animals a nuisance. Many farmers therefore prevent the development of the horns by destroying the "button" in the young animal by means of alkali or other chemicals. Occasionally, however, there appears an animal without horns; the Polled Angus was a "sport" of this kind. Polled, or hornless, individuals have appeared also among Jersey and Hereford stocks. If a polled individual is mated with one that has horns, all the offspring will lack horns. That is, the polled condition is dominant. A *purebred* hornless bull may thus become the father of whole herds of hornless cattle. But if *hybrid* polled animals are mated, the following generation will show segregation in the way already described for the yellow-green color contrast in peas and for other plant characters (see illustrations, pp. 476 and 477).

In sheep-raising certain kinds of fleece are found to be more profitable than others. In order to combine merino wool with hornlessness it would be necessary to find out by means of breeding experiments which characters are dominant and which recessive. In three generations we could then establish new breeds having the desired combination.

In actual practice the matter is, of course, not quite so simple. Some of the characteristics in which we are interested may depend upon the presence





Bureau of Plant Industry, United States Department of Agriculture

HYBRID CORN

Each variety of hybrid corn has special advantages over older varieties, but the grain cannot be used as seed

of two or more genes. There is also the fact of linkage, which holds together through the generations two or more characters, of which one may suit us while the others are quite undesirable. In mammals, for example, genes for coat-colors and genes for ear-defects are curiously linked and so place a limit on carrying out what we intend in animal-breeding. Nevertheless breeders systematically apply the principles of genetics to produce new varieties of animals, that is, *combinations* of qualities that have never appeared before. The Orpington fowl is an artificial breed of this kind, and new breeds are constantly being brought out. And as in the case of plants, breeders supply young hybrid poultry having desired characteristics, but not capable of passing on these qualities.

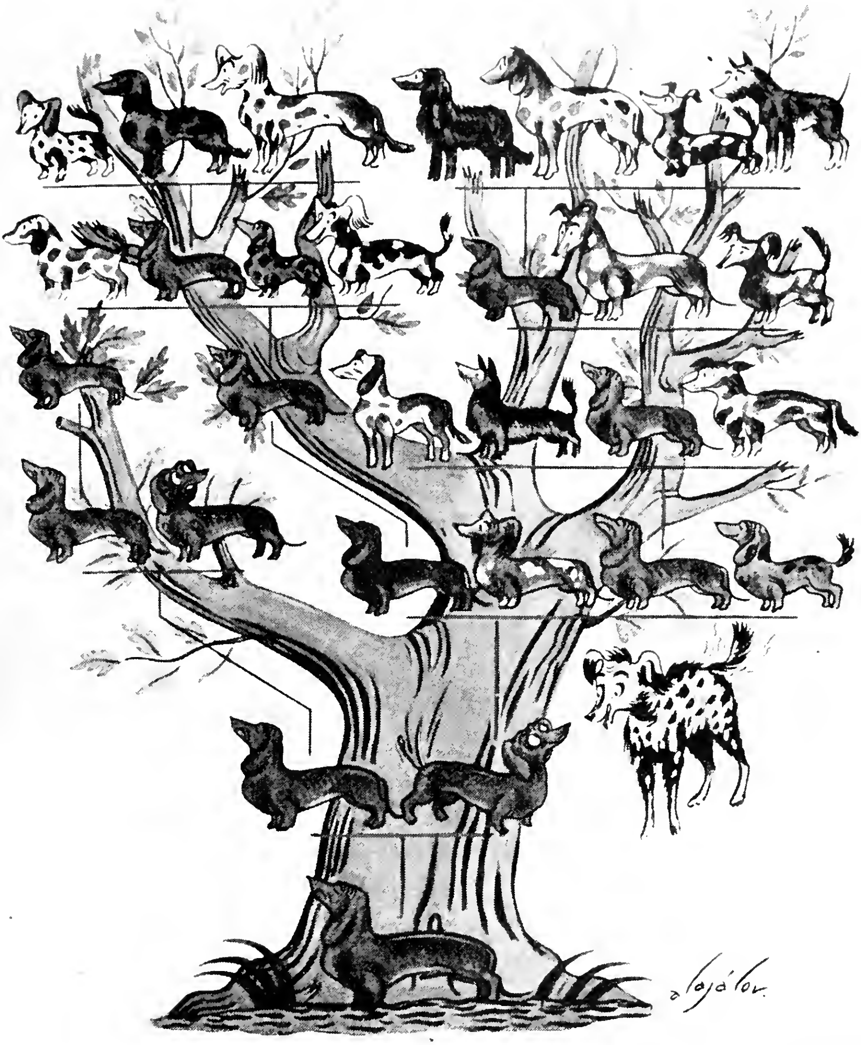
Heredity in Man[1] So far as reliable facts are available, heredity seems to follow the same course among human beings as among other organisms (see table below).

Human beings take a comparatively long time to mature. To get complete records for many generations it would be necessary to go back several

Heredity in Man

DOMINANT CHARACTER	RECESSIVE CHARACTER
Curly hair	Straight hair
Dark hair	Light; red
Beaded hair	Even hair
Hairlessness, associated with lack of teeth	Normal condition
White forelock	Normal, even coloring
Brown eyes	Blue eyes
Normal sight	Night blindness
Hereditary cataract	Normal eye
Normal hearing	Deaf-mutism
Normal ear	Otosclerosis
Normal pigmentation	Albinism
Hapsburg lip	Normal lip
Normal muscular tone	Low muscular tone
Nervous temperament	Phlegmatic temperament
Fused fingers or toes	Normal digits
Supernumerary digits	Normal number
Broad fingers (lacking one joint)	Normal length
Fused joints of digits	Normal joints
Double-jointedness	Normal condition
Normal growth	General dwarfing
Limb dwarfing	Normal proportion
Immunity to poison ivy	Susceptibility to poison ivy
SEX-LINKED CHARACTERS	
Normal blood	Hemophilia
Normal hair	Baldness
Normal vision	Color-blindness

[1]See No. 7, p. 505.



BREEDING FOR UTILITY AND FOR SPORT

Animal-breeders are constantly producing new varieties by combining in "homozygous" individuals the qualities considered of value. They start with individuals having desired characteristics and produce hybrids. In subsequent generations the desired qualities are recombined, the undesirable ones eliminated

centuries; and such records were not being kept so long ago. The number of offspring in human matings is comparatively small. We can therefore never get even a hint of all the possible character-combinations in any one family. Since human mating normally involves so many elements of taste, sentiment, affection, and other feelings and values, experiments are out of the question among free people. Finally, what we call the human race is really a mixture of many distinct types or combinations of characters, and these are so thoroughly mixed up that we cannot find a "pure" race of human beings at the present time. It has nevertheless been possible to compare the facts obtained from family records with the behavior of various characteristics in the pedigrees of plants and animals. Such studies show that many human characters reappear in families according to the hereditary principles of dominance, segregation, recombination, and linkage.

We shall probably apply our knowledge of heredity to human affairs along the line of showing what types of marriage are likely to produce offspring with one or another undesirable trait. We already know that certain abnormalities of physical structure or mentality are transmitted in a definite way. We therefore counsel men and women in whose families certain undesirable recessive characteristics appear not to marry others of similar stock. In the course of time we shall no doubt develop certain standards of fitness for marriage which will be enforced largely by the same kind of public opinion and tradition as now distinguish the customs of different peoples.

In Brief

Of the many characteristics, or traits, present in any organism, certain ones are transmitted, or inherited, independently of certain others.

With regard to a pair of alternative traits, a hybrid may resemble one parent completely, presenting the dominant character, and not show in its appearance or behavior the possibility of transmitting the alternative recessive quality.

Individuals that are pure-recessive for a given character breed true, as do individuals that are pure-dominant; but hybrids cannot transmit the dominant character to all their offspring. Matings of hybrids result in segregation, or a breaking up of the *combinations* of characters derived from different ancestors.

To say that a plant or animal has inherited certain characters from the parents means that there is something in the zygote, or fertilized egg, which makes possible the development of those traits, and that whatever is in the zygote must have come from the gametes and so, presumably, from the parents.

The recurrence and disappearance of certain peculiar traits in successive generations agrees with the behavior of the chromosomes in plants and animals during the formation of gametes, during fertilization, and during develop-

ment. It has been helpful, accordingly, to assume that each inheritable trait depends upon something in one of the chromosomes.

Specific determiners, or genes, are apparently arranged in each chromosome in a series, like beads on a string. The genes, or determiners, in each chromosome tend to remain associated, or linked, although they may be transmitted independently.

Although the inheritance of characteristics and the behavior of the chromosomes are remarkably parallel, it is probable that each "character" depends upon the interaction of several genes, and that each determiner produces several effects in addition to the one we happen to observe.

The chief problem in dealing with plants and animals, from the breeders' point of view, is to get organisms that can transmit combinations of desirable qualities. Breeders and experimenters have succeeded in producing strains that maintain such combinations, quite distinct from any "natural" species.

EXPLORATIONS AND PROJECTS

1 To study the inheritance of certain traits in rats, cross a hooded rat with an albino; then mate the hybrid generations among themselves. Tabulate the results for the two successive generations. Compare the distinctive traits in parental, first-hybrid, and second-hybrid generations. Interpret results.

2 To study the inheritance of traits in guinea-pigs, cross male and female pigs having contrasting characters, such as rough coats versus smooth coats, long hair versus short hair, solid color versus spotted appearance, agouti versus nonagouti, or black versus albinism.[1] Tabulate results and note conclusions as to which traits are dominant and which recessive.

3 To demonstrate the 1:2:1 ratio by chance combination, work in pairs and flip two coins 100 times. Record the heads and tails for each double throw. The theoretical ratios are both heads, 25 times; 1 head, 1 tail, 50 times; both tails, 25 times. Compare results with the theoretical expectations. Combine the results of several sets of trials; compare the total with the theoretical expectations. Note unusual deviations from "expected" results.

4 To work out interpretations and probabilities in hereditary phenomena, make diagrams and calculations in various concrete or imaginary situations, such as the following:

a. Pure smooth peas are crossed with pure wrinkled peas. Note (1) the appearance of the hybrid generation; (2) the genetic make-up of hybrids. (Use capital *S* to represent dominant smoothness and small *s* to represent recessive wrinkledness.) Show (1) the probable appearances in the following generation if the hybrid individuals are mated; (2) the genetic make-up of the various types; and (3) the ratios of the different phenotypes and the ratios of the different genotypes.

[1]The gestation period in guinea-pigs is 65 days. The pigs can be fed on the complete diet as given on page 112, or upon commercial rabbit chows supplemented by green foods and milk. If green grass or clover is available, it may well constitute the bulk of the diet.

b. Pure smooth green peas are crossed with pure wrinkled yellow peas. What will be the appearance of the hybrid generation? the genetic make-up? (Let capital Y and S represent the dominant yellowness and smoothness respectively, and small y and s represent the recessive greenness and wrinkledness.) Note (1) the appearance of offspring; (2) the kinds of gametes that the hybrid generation will bear. Work out the results of crossing these gametes, using the "checkerboard" or Punnett squares.

c. Pure dominant strains of tall smooth yellow peas are crossed with short wrinkled green peas. Use the Punnett-squares method to find (1) the appearance of the hybrid generation; (2) the genetic make-up of the hybrid; (3) the possible gamete types produced by these hybrids; (4) the different phenotypes produced; (5) the ratios among the body types in the offspring; and (6) which types will breed true in later generations, and which will break up again.

d. A child of brown-eyed parents has blue eyes. Show by the use of genetic symbols and a diagram the probable composition of immediate ancestry.

e. Henry and Susan both have normal hearing. One of Henry's grandparents was a deaf-mute; among Susan's near relatives two first cousins are deaf-mutes. Show by diagram and genetic symbols the possibility that, should Henry and Susan marry, some of their children might be deaf-mutes.

f. What would be the expected offspring of a mating of a long-haired guinea-pig with a short-haired guinea-pig one of whose parents was long-haired?

g. A rough-coated black guinea-pig whose mother was smooth-white is mated with a smooth-white animal. Work out the kinds of offspring and the ratios of the various kinds.

h. A girl of normal vision whose father was color-blind marries a color-blind man. Work out the probabilities as to color-blindness among their sons and daughters.

5 To study the inheritance of traits in fruit flies, cross the wild type with pure cultures showing characters readily distinguishable without a microscope. Such characters as ebony body and vestigial wings illustrate Mendelian inheritance; white eyes and yellow body illustrate sex-linked inheritance.

In mating, it is essential to use only virgin females. Since adults in a given culture mate within a few hours after emerging from the pupa, use only cultures in which there are no adults over an hour old. To cross, select one male and one virgin female, from etherized cultures.[1] Place pair in a prepared bottle containing suitable food.[2] After eight to ten days remove these parents so that there is no chance for them to

[1]For etherizing, use a bottle the same size as the culture bottles (widemouthed, 8 oz, or half-pint milk bottle); attach a wad of cotton to a cork with a wire. Moisten cotton with ether. Transfer flies from culture to bottle; close and etherize one minute. Dump insects on a piece of clean paper and sort with a camel's-hair brush. The females have a slightly wider abdomen than the males and also small lines across the tip of the abdomen; the males, which are smaller, have a black-tipped abdomen. To prevent the growth of mold, use the commercial preparation "Moldex".

[2]To make a growing medium, add 100 g of corn meal, $\frac{3}{4}$ cup of molasses, and 15 g of agar to 750 g of boiling water, while stirring. Cook about 10 minutes. Pour into sterilized bottles, about $\frac{1}{2}$ in. in each; then insert in each a strip of paper toweling, on which the larvae may crawl to pupate. With a clean medicine-dropper add to each bottle one drop of water in which a bit of yeast cake has been dissolved.

mate with the emerging hybrid flies.[1] For the second generation, simply transfer several hybrid male and female flies to new bottles. Again remove the adults after they have laid their eggs.

6 To study the inheritance of traits in poultry, incubate hybrid eggs of known parentage and brood the chicks in the classroom or at home. (The inheritance of the barred factor in the sex-chromosome can be demonstrated by crossing a Rhode Island Red rooster and a Barred Rock hen.) Describe appearance of cockerels and pullets. Account for the results you obtained.

7 To trace the probable inheritance of human traits, collect evidence as to the occurrence of various traits in the members of a family. Distinguish those characteristics which seem certainly to be inherited as dominant or as recessive. Note any evidence that a trait may be inherited but remain undeveloped under special conditions. Note any evidence as to whether a child inherits more traits from the parent of the same sex than from the parent of the opposite sex.

QUESTIONS

1 How has hybridizing been used to improve our plants and animals? What are its advantages? its limitations?

2 What is it that actually continues from one generation to the next, in sexual reproduction?

3 How can the changes in the chromosomes be related to the simple Mendelian laws of dominance, segregation, and independent assortment?

4 In what sense are the facts of linkage, imperfect dominance, and multiple factors exceptions to the Mendelian laws?

5 How does a further study of these seeming exceptions strengthen the hypothesis that the bearers of heredity are in the chromosomes?

6 How is it that individuals sometimes lack qualities which are present in one or both of the parents?

7 How can an individual sometimes manifest qualities which neither of the parents has?

8 How do the common fruits and vegetables in use today differ from those of a generation ago? How did the changes come about?

9 What are the necessary steps in establishing a new breed of plants or animals?

10 What advantages has the plant-breeder over the animal-breeder?

11 How does our present knowledge of heredity agree with the idea that offspring inherit the effects of experience, exercise, injury, sickness, and other modifications?

12 In what way can the experience or condition of a pregnant female influence the offspring?

[1] Ordinarily it takes about two weeks for the fruit fly to complete its life cycle, though in an incubator at from 75° F to 80° F it takes from 10 to 12 days.

1. What causes new species to arise?
2. How do new species come to fit their surroundings?
3. Are modern plants and animals superior to ancient forms?
4. How can we tell whether any kind of plant or animal is really a new species?
5. What kinds of variations are inherited?
6. Why are some variations more fit than others?
7. Does the human race consist of one or of several species?
8. How can we tell whether man has resulted from evolution?
9. What is meant by a "missing link"?
10. Is evolution taking place today?

All life is one. Every plant is like all other plants, every animal is like every other—in the basic capacities. That is, each grows, develops, responds adaptively to what goes on around it, reproduces.

Yet every individual is unique. Indeed, the individual is all that we can know directly—the individual, and many other individuals more or less like it. From our experience with many unique individuals we may feel that we know whole classes of similar individuals. We speak with confidence of the cat or dog family, of the class "fishes", of the order "beetles", or of all mankind.

Since individuals resemble their parents and other ancestors, they form groups that remain fairly constant through many generations. But individuals also differ from their parents, as well as from each other. The actual constitution of a species or of a genus is constantly changing, just as the exact chemical make-up of an individual is constantly changing. But does this process bring about the formation of new species? And how, in spite of such changes, do living things continue to be adjusted to their surroundings?

How Can New Species Arise Out of Old Ones?

New Species or New Individuals There can be no doubt that species of plants and animals became extinct throughout ancient times, and that new species came into being from time to time. How can a new species arise ready-made, with a complete set of individuals at all stages of development, like the inhabitants of a beehive? But it is no easier to imagine a species starting out as a pair of adults, or as a number of eggs, which would first have to develop into adults and then reproduce themselves. Cuvier cut across all such difficulties by saying simply that when the time came, new species were created, and they repopulated the world. And the new species, he was sure, had no connection whatever with their predecessors, although they had been created along similar lines.

If we assume, with Darwin and Lamarck, that life has been continuous, then we have to answer the question How did different forms come to be? We know that individuals differ from their parents, but will their offspring differ still more from the grandparents? And will individuals in such a line of descent ever differ enough from their ancestors to be a new species?

The Germ Plasm The basic question is, of course, What connection is there between an organism and the germ cells which it bears? or What connection is there between a fertilized egg and the individual into which it develops? These questions could not be effectively considered until after the essential facts of fertilization had become known. According to the German zoologist, August Weismann (1834–1914), each organism is what it is because it developed from a certain germ plasm (see illustration, p. 508).

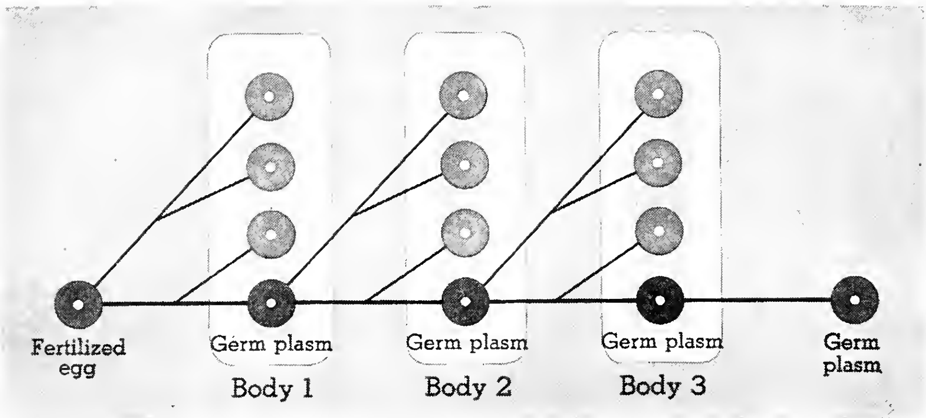
It was Weismann's notion that the experience of an individual cannot influence the germ cells so as to make the offspring show the effects. The result of exercise or of mutilations or of sickness, for example, should *not* appear in the following generation. There is, in fact, no evidence whatever that modifications produced in the course of an individual's lifetime ever appear in the offspring, although many people firmly believe that such modifications are actually passed on.

In human beings and in other mammals, illness, alcoholism, or chemical injury to the parent may bring about some effects in the offspring. But such effects are not generally of the same kind in the child as in the parent. It is easier to explain what happens in such cases as an injury that interferes with the development of the fetus.

It is, of course, impossible to prove a negative—that acquired characteristics are *not* inherited (see page 342). The most that we can say about Lamarck's assumption is that no one has yet shown unmistakably that acquired traits have been transmitted. But we have learned from countless experiments since the time of Weismann that the chromosomes appear to be constant and that the "genes" appear to be unchanged by the experience of the body.

What Kinds of Differences Are Inherited? When Weismann made the distinction between germ plasm and soma, or body plasm, he anticipated important later discoveries about the behavior of cell chromosomes (see pages 368 and 386). We can now say with assurance that those qualities which are determined by the germ substance or genes *are* inherited, whereas the effects of experience or of external forces—which do not affect the germ —are *not* inherited.

We recognize, of course, that parents never actually hand over to their offspring particular features. Mother still has her curly hair; father still has his round chin. Parents transmit a certain *germinal constitution*. In order to decide in any case how a particular organism came to be just as it is at the mo-



After Weismann

THE IDEA OF GERM PLASM

We commonly think of germ cells as produced by the organisms which bear them. We may also think of the fertilized egg as dividing into cells that become a body and others that continue as germ plasm, which later gives rise to new individuals — and more germ plasm. The stream of germ material persists indefinitely, carried through successive generations in the bodies — which it produces

ment, it is not enough to compare two individuals or two groups of individuals. The problem really involves four sets of questions. We can see this if we generalize it to cover all essentials.

1. How do organisms of *uniform* genetic constitution develop in environment *A*?

2. How do organisms of *uniform* genetic constitution develop in environment *B*?

3. What is the effect of a particular environment upon the development of organisms having constitution *C*?

4. What is the effect of the same environment upon the development of organisms having constitution *D*?

These are practical questions for all who have to raise plants or animals, as well as for breeders. Some varieties or strains of plants and some kinds of animals—including human beings—can thrive in one setting but not in another. We invite failure if we plan to raise bananas in Kansas or to run a fox farm in Florida. But we have to be discriminating even if we plan to raise wheat or corn in Kansas and oranges in Florida.

The physician and the nurse, the politician and the teacher (as well as the poultryman or the rancher), have to know that you cannot treat all individuals alike if the individuals are to develop to their full capacities. The old saying that you cannot make a silk purse out of a sow's ear still holds true. We must recognize that individuals of one constitution will make aviators,

but individuals of a different constitution will do better as composers or inventors.

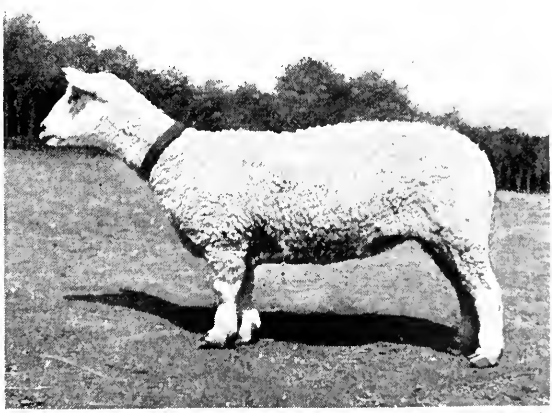
The individual differences that correspond to "constitution" are due to inherited genes. A particular constitution or talent may never be transmitted as a whole, since it results from the interaction of many genes—some dominant and some recessive. Individuals will thus continue to differ from their parents, but they will not deviate in a consistent direction because of similar experience, as Lamarck thought. Nor will they deviate in a consistent direction because of selection, as Darwin thought. The species remains constant, just as the level of the sea remains constant, or the composition of the blood, *on the average*—that is, through constant fluctuations.

If Species Are Constant, How Can New Forms Arise?

Sports From time to time animal-breeders and horticulturists report the appearance of an individual that is in some respect strikingly different from his ancestors. Such an individual is a "sport" and it is often a deformed plant or animal which cannot live very long. Or it may be strong enough to survive, a freak like those exhibited in the side show of a circus. In many cases, however, a sport has some valuable or interesting qualities that the breeders seek to preserve.

There appeared on a farm in Massachusetts, in 1791, a queer sheep with a long body and very short, crooked legs. This freak, ancon sheep was not particularly handsome. When it had grown up the owner considered the odd shape of value. It kept the animal from jumping fences. By using this sport as one of the parents for a new flock he obtained in the course of years an increasing number of these short-legged sheep (see illustration below). The original ancon breed was kept going about a hundred years. More recently

There are no known descendants of the original ancon ram that suddenly appeared on a Massachusetts farm in 1791. More valuable sheep sports have since appeared and have become established, but the ancon remains of interest as a classic example of a breed's becoming established through the selection of a recessive character that started as a freak or sport. The ancon mutation in the picture appeared on a farm in Norway, in 1919



Christian Wriedt

A CLASSIC TYPE OF MUTATION

the same type of sport has again appeared in this country and in Sweden. This "turnspit" type of animal is sometimes found among dogs, the Dachshund being a common example.

At other times there have appeared sheep with unusually long wool, and these were saved as a basis for further breeding. Peacock fanciers sometimes find a single bird with plain black plumage. Several times whole flocks of such birds have been established from a single freak mated with the normal type. These sports, or jumps, occur also in plants. A wild dewberry without thorns was the basis for Luther Burbank's thornless blackberry. A grain stalk may appear without the sharp bristles, or awns, among the grains. A seedless plum or a seedless orange grows unexpectedly upon a tree that had previously borne only respectable fruit with seeds.

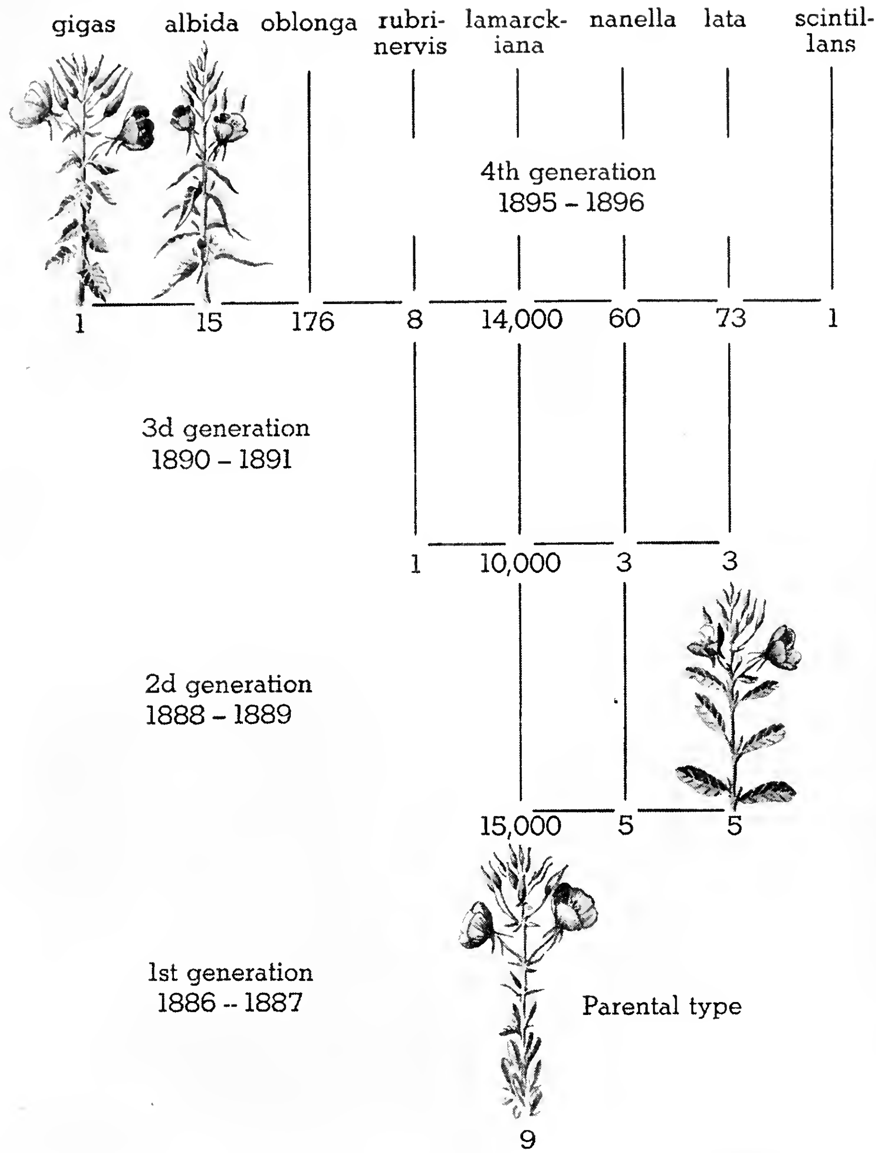
Mutations[1] Darwin knew of such sports, but looked upon them as freaks rather than as significant features in the formation of species. In more recent years biologists have been giving special attention to sports. From the fact that such freak individuals sometimes establish distinct lines of descendants, the Dutch botanist Hugo de Vries developed a theory to account for the origin of new species. De Vries himself cultivated many lines of new plants which originated in this sudden or discontinuous manner from evening primroses and from other species, both wild and cultivated (see illustration opposite). Such suddenly arising departures from the parental type de Vries called *mutations*. The individuals bearing the new characters for the first time are called *mutants*—from a Latin word meaning "to change".

In most cases, the observed mutants do not deviate greatly from their parents. The changes are usually confined to one or a few details, such as shape or coloration or size or the number of like parts. Nor are most of the mutations observed of any great importance, either as natural advantage to the organism or as useful in practical cultivation.

The mutation theory does not attempt to explain how it is that plants and animals do depart from the parent types. It declares merely that new types become established only if individuals appear with *distinctive qualities* which they, in turn, transmit to *their* offspring. It does not assume that mutants have any superiority or advantage over the parental type, although some may have. It is sufficient for the theory if new types of individuals *are capable of living and of establishing themselves* through their progeny. This theory, like the theory of Lamarck and the theory of Darwin (see pages 464 and 466), depends upon the facts of *heredity*.

We know definitely that such jumps occur. We do not know what brings about such freak behavior during the reproduction of plants and animals. We know merely that such a jump away from the ancestral line is, in effect, the beginning of a new species.

[1]See page 522.



MUTATIONS IN THE EVENING PRIMROSE

From 1886 on, Hugo de Vries planted seeds from the common evening primrose. Among thousands of new plants grown each year he found from one to several individuals that departed in some definite way from the parental type. He gathered and planted the seeds of these deviates, and in the course of time had a number of distinct strains. From these experiences he developed the mutation theory to explain how new species originate

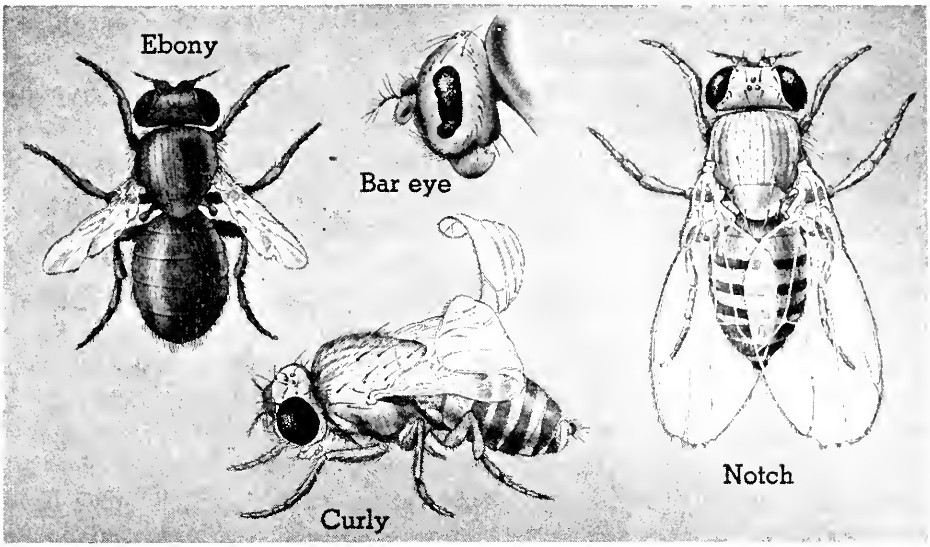
Mutations under Glass Practical breeders and horticulturists bring into the market every year beautiful new colorings among flowers and new varieties of prize-winning animals. But most of these novelties do not continue long. They are replaced by other novelties. Sometimes this is a matter of fashion and interest. At other times, however, the breeders are unable to maintain a consistent variety for several generations. This has been the case especially when novelties have arisen as the result of mating two different lines. These hybrids are said to break up in succeeding generations, or to throw back to the ancestral characteristics. The tremendous improvement in our understanding of heredity since the beginning of the century has made it possible to follow closely plants and animals under controlled conditions.

Among the most intensively studied animals were the famous fruit flies of Professor Thomas H. Morgan (1866–), of Columbia University and later of the California Institute of Technology. The fruit flies are of no known value in practical affairs. They were used only for convenience, for they can be kept in large numbers in a comparatively small space. They have distinct characteristics, which make it easy to study them with reference to particular traits. And they reproduce at short intervals so that some twenty-five generations a year can be studied without too great cost or effort.

Under these controlled conditions, Morgan and his associates were able to observe in almost every generation from one to several mutations. Some of the departures from the ancestral pattern reappeared in subsequent generations. In considering the rise and reproduction of these various fruit flies, no question is raised as to the *adaptive* value of the new qualities. In many cases, indeed, the freak was unable to reach maturity or to reproduce itself. Nor for the moment was any question raised as to what feature in the general environment, in the food, or in the strain itself brought about such mutations. It was necessary merely to make sure that the freak arose in a "pure line"—that is, was not itself the result of crossing, or "hybridizing"—and that the new characters reappeared in the offspring.

Similar observations have been made with many kinds of plants, as well as with other animals, in all parts of the world. Literally thousands of mutations have been described, and they have furnished a valuable basis for the interpretation of the problems of inheritance.

Mutations in the Making Speculation as to the cause of a mutation led to experiments with the various factors of the environment. The effects of temperature, chemical conditions, dryness, changes in the food, have all been tried. In 1928 H. J. Muller (1901–), then of the University of Texas and since working in research laboratories in different parts of the world, showed that under certain conditions X rays produced marked effects upon the germ substance of mature fruit flies. Treating cultures of insects with X rays increased the proportion of mutations in the following generation. This



After Morgan

MUTATIONS OF THE FRUIT-FLY

In the course of systematic observation and experimenting, Morgan and his associates found hundreds of individual fruitflies that arose as distinct types year after year. They differed from their parents in a single character, sometimes in several characters — eye color, wing shape, body color or shape, and many other details

showed at least that without modifying the parent, something may happen to the germ cells in a way that alters the characteristics of the offspring. It did not enable us to produce particular mutations at will, nor did it tell us exactly how the X rays exert their influence. Among these mutants, as among those which appeared "naturally" in the laboratories of other investigators, were some with white eyes, some with smaller wings, and many other freaks. Many of these were entirely new in the sense that they had not been found by other experimenters or observed to occur "naturally".

In recent years startling results have been produced by treating plants with the drug *colchicine*, obtained from a plant of the crocus family. The first effect observed is a great increase in the size of parts treated, often associated with coarse tissues or rank growth. The giant character is inherited. Closer study indicates that the colchicine acts upon cells at the time the nucleus divides, by keeping newly formed chromosomes from separating into two sets. The result is a doubling of the chromosomes, and a modifying of the growth and other characteristics. A "harvest spray" containing colchicine has been used to keep apples of McIntosh and other varieties from dropping off the stem too soon while ripening. This spray improves the quality as well as the yield, from the orchardist's point of view.

We have every reason to think that new forms are constantly arising, more

rapidly in some regions or among some species than in others. None of the physical or chemical features in the conditions of living is known to give rise to mutations. Some of the mutations certainly are incapable of perpetuating themselves. From the facts that we do know, however, it seems reasonable to assume that (1) mutations have taken place among living things throughout the centuries; (2) some of the existing species arose, through mutation, from ancestors having somewhat different characteristics.

Does the Idea of Evolution Apply to Human Beings?

Kinds of Resemblances On the basis of structure and form, human beings are most like the apes and monkeys. For the zoologist *Homo sapiens* represents one family of the order Anthropoidea. The other families of this order are represented by the marmosets, the New World monkeys, the Old World monkeys, and the simians, or apes (see p. 53 and Appendix). We have seen that in hundreds of details the homologies of structure show remarkable similarities between man and the other mammals, but more specifically the other anthropoids. The teeth, for example, vary among the primate families, but the numbers and kinds of teeth are the same in men and the apes.

In the course of its development the human embryo passes through stages which are impressively like those of other vertebrates, of other mammals, and especially, again, of the other primates (see illustration, p. 459). During this development the embryo puts on details of structure that recall details in other species, but that have no relation to the human mode of life (see pages 174 and 460). We might conceive all these resemblances to be merely coincidences, and without any bearing upon man's history or ancestry.

Chemical Resemblances Some of the similarities between man and the other primates, however, appear more significant. The human race, as a whole, is immune to certain species of microbes that cause disease in other species, but the apes are susceptible to about the same diseases as men are. That is, there is a chemical similarity between man and the other primates, as well as a physical, or structural, similarity. The parasitic protozoon that causes the disease syphilis affects other primates, but with a virulence that is almost *in direct proportion to their structural resemblance* to man: the resemblance is strongest in apes, weaker in monkeys.

We have seen that bringing foreign substances into the blood of an animal leads to the formation of specific antibodies (see page 233). White-of-egg, for example, would result in one kind of antibody, and the protein of a fish would result in a different kind. This general fact was at first put to practical use in deciding whether blood-stains had been made by human blood or by the blood of some other animal.

If small quantities of human blood are repeatedly injected into a rabbit

over a period of time, the rabbit's body will form specific antibodies that will produce a cloudiness if mixed with human blood. The antibody is said to "precipitate" the specific human protein, but the rabbit's serum will not react in this way with the blood of a hen or a sheep. But it will precipitate—somewhat—if mixed with monkey blood. And it will precipitate more if mixed with ape blood (see page 240).

These and similar experiments carried on over many years show that the structural resemblances between animals which we class as "related" have their parallel in chemical resemblances. The blood of man is more like that of an ape than it is like the blood of a monkey, and it is more like the blood of a monkey than it is like that of a lemur.

In structure, in the common functions, in development, in chemical peculiarities, and in genetic behavior man is like other organisms. And the degree of resemblance, as well as the degrees of difference, warrants us in thinking that man is subject to the same forces or influences as have brought about transformations in other species.

Evolution and Man At the close of the last century thinking people were discussing the evolution theory as applied to man. Many who were willing to assume that evolution had taken place among plants and lower animals hesitated to accept the same explanation for the appearance of man upon earth. One of the strongest arguments urged against the theory was the fact that it had been impossible to produce a complete record of a graded series connecting men of today with his supposed nonhuman or prehuman ancestors.

This argument of the "missing link" carried a great deal of weight. For most people do not appreciate how unlikely it would be for a complete series of specimens to be preserved through the far-reaching changes which the earth itself has undergone. Of the millions of human beings and other vertebrates that die in a given region during a century, how many skeletons are likely to remain sufficiently intact to be recognized from ten to fifty thousand years later? From a scientific point of view, it would be sufficient if the scattered pieces found at widely different levels (geological ages) did actually fit in with a *supposed* series.

The few bones found in Java in the early eighteen-nineties by the Dutch army surgeon Eugène Dubois (1858–1940) fit into such a series in a very satisfactory way. The type of animal to which these bones belong was named *Pithecanthropus erectus*, and probably represents a "missing link." This animal had among his contemporaries a form of elephant, rhinoceros, Indian hippopotamus, tapir, hyena, a deer, and an animal somewhere between a tiger and a lion. The climate and vegetation were similar in many ways to those we now find in southern India and the islands of the region.

A later discovery of ancient remains in Sussex (England) seems to point

to a more closely related ancestor. The skull is larger than that of Pithecanthropus, and the teeth are more like those of modern man (see illustrations, pp. 51 and 52).

In various parts of France, Germany and Belgium large numbers of specimens have been found that belong apparently to the same races of primitive men. The first of these was found in a cave in the Neanderthal in Germany, in 1856. The type is frequently referred to as the Neanderthal race. These men had much larger skulls than the Piltdown man of Sussex—larger even than the skull of races living today. However, the jaws and teeth, the low and retreating forehead, the prominent ridges over the eyes, and other features indicate an earlier stage of development. This group has been named *Homo primigenius*, or *Homo neanderthalensis*. More recently, teeth and fragments of skull dug up in eastern China have led anthropologists to construct what is probably an earlier member of the human family, the Pekin man.

Human Races From a biological point of view, all human beings belong to the same species, in spite of the great variations among the distinguishable "races". There is complete fertility among all varieties and stocks, and the hybrids, or progeny of any crossings, are normally fertile.

Classifying the races of man becomes more difficult rather than easier as our knowledge increases. A few centuries ago European travelers could report that they had seen strange peoples of various colors, and several races were accordingly listed in the geography books. Today, however, every attempt to classify human races breaks down completely because "types" overlap so much and there are such extensive mixtures of hereditary traits. The first difficulty, of course, is to find a basis for classification. The color of the skin is the most obvious difference. We may start out confidently to speak of the white, or Caucasian, race, the black, or Negroid, race, and the yellow, or Mongolian, race. But we are immediately reminded of the dark-skinned inhabitants of India and southwestern Asia, who are just as truly Caucasians as are the "Nordics" of England or the state of Georgia.

Shall we consider the straightness or curliness of the hair? The Negroes of Africa and the Melanesian islands typically have woolly hair. But so have many fair-skinned and yellow-haired and blue-eyed families of nearly every European country, as well as of our own country. Shall we be guided by the shape of the head? The Nordics, the Mediterraneans and the Hindus have narrow heads. But so have all the main divisions of mankind. At the same time, broad heads are typical of the Alpine whites, the Mongolians, and the small Negroid tribes. Is tallness or shortness a suitable basis for separating races? Among the taller strains in the human population are certain Negro tribes, the Polynesians, the North American Indians, and the north Europeans. That is to say, whites, Negroids, and Mongolians come in tall, medium, and short strains.

Brown Brothers; H. L. Shapiro; American Museum of Natural History

Black Brown Yellow Red

SORTING PEOPLE BY COLOR

Differences in skin color are obvious enough — except where shades or colors blend. We cannot find any color group in which the members are so much alike in most of the other characters as to be considered "of the same kind". Nor do those who differ in color differ consistently in most of the other characters, so as to be considered "a different kind"

The medical students of the Caucasian University at Tiflis (shown in the illustration on page 67) are probably all of "Caucasian" stock. To what extent are they essentially alike as to stature, or pigmentation, or the character of the hair, or the shape of the head—or any other trait? For that matter, what physical characteristics have these students in common that are not found also among yellow, black, red, or brown people?

As with other species, inbreeding for many generations is likely to establish a fairly uniform type of human beings in any given locality. There are indeed many villages or tribes in which nearly the entire population has some distinguishing physical characteristics, just as a particular region may show a distinct dialect or idiom. In the course of centuries not only have the main "races" been formed, but also subraces and specialized stocks. The North American Indians, for example, are unquestionably descendants of ancient Mongolians who came either across the land bridge from Siberia to Alaska, or perhaps by boat. After many centuries they had spread southward into South America and had also moved eastward toward the Atlantic coast and the islands off Florida. When the Europeans first came to America, they found relics of very old civilizations in Peru and Mexico. They also found scattered over the continent other "Indians" who differed from the Mexican and South American Indians both in physical features and in their modes of life. And to this day another branch made up of the Eskimos is obviously different physically and in its mode of life.

Among the North American Indians there are several distinct branches which apparently became separated from the main stem many generations ago. While we have no pure race, there are many such isolated stocks that

are fairly consistent. This means probably that generations of inbreeding have separated out a population which has several distinctive characters in a homozygous state, that is, either pure dominant or pure recessive.

Human Hybrids From the earliest times of which we have any record, tribes everywhere seem to have had rules intended to keep the population "pure". That is, peoples tried to guard against "contamination" by foreign blood. Every tribe, every village, was the very center of its own universe, and each cherished legends regarding its origin through a special act of the gods. All strangers were likely to be enemies. In the course of time, tribes have become amalgamated into larger units. Hostility toward outsiders and loyalty to insiders gradually consolidated neighboring groups into larger federations and nations. The many tribal myths which made each fairly distinct group feel itself to be God's chosen people had to be expanded to fit the nation. Today, however, neither the facts of history nor the facts of biology can justify us in identifying race with nation.

Human types have apparently always crossed wherever two or more tribes came close together, whether through war or commerce. In modern times, with the amount of travel tremendously increasing through larger and swifter cars, boats and airplanes, there has been more and more intercrossing of stocks. As a result, there are more kinds of "hybrids" and also subsequent segregation and distribution of distinctive physical traits. In a mixed crowd in every large city you can see faces that you recognize as coming from faraway regions. And you can see many individuals whom it is quite impossible to assign to any particular nation or even "race". Eyes and noses and lips and chins and head shapes and cheek bones have been brought together from all parts of the world in new combinations (see illustration opposite).

Many of the distinct traits that we see in human beings must result from a multiplicity of factors or genes, since there is a great deal of "blending". We may observe almost perfectly continuous gradings in the various characters, such as stature, coloring of skin, hair and eye, proportions of the head, and shapes of the various features. Today we must search in out-of-the-way places for examples of "pure" strains, and explorations by airplane will no doubt continue to reveal isolated groups of human beings — like the village of "white Indians" found in Central America before the Second World War.

As in other species, hybridizing among human beings shows no effects that are uniformly advantageous or disadvantageous. In many cases, indeed, the offspring of mixed marriages do "combine the best features of both" parental stocks. Those who have feared the possible ill effects of racial mixture seem to have been influenced by group pride or feelings of superiority rather than by any actual knowledge of the outcome of crossing. All kinds of crossings seem to produce harmonious combinations.

American Museum of Natural History

WHERE DO THESE COME FROM?

Here are several American citizens who acknowledge their European ancestry. Which can we definitely recognize as "Nordic", which as Spanish, or Russian, or Scandinavian, or Scotch, or French, or Italian? How can we recognize them?

Human Types and Cultures The process which has been going on in our American "melting pot" has been going on also along the world's highways. In Paris, Capetown, or Singapore one can easily recognize an "American". But a sample of such wandering Americans would show almost as great a variation in stature, complexion, coloring, hair, and other physical features as samples taken at random from various nations or "races". What makes them all recognizable as Americans? Apparently it is not so much distinct physical characteristics as something in their *manner* and *bearing*. It is these subtler elements of behavior that distinguish modern groups. And the anthropologists have found it much more satisfactory to consider prehistoric and early historic mankind from this same point of view, distinguishing *cultures* rather than separate *races*.

Over large areas and for long periods there has been great consistency in types of pottery, basketry, housebuilding, tools and weapons, as well as in types of language, religion, customs, ceremonials and beliefs. That is, peoples have remained distinct in what they *make* and *do*. There has been no corresponding agreement in physical characteristics. On the one hand, distinct physical types may share in a particular culture. Many different kinds of human "organisms" may act in much the same way, think in the same way,

have similar attitudes toward the various things that appear important in life. On the other hand, people of the same physical type may carry on totally different modes of life in different parts of the world, or in different ages. They not only speak different languages, but may have quite different ideas about the world and different ideals about values and goals. At the same time, a study of living races shows very little consistent variation in the internal organs or even in the bones, corresponding to recognizable types. There is no evidence whatever that the human organism has changed in any essential detail in the past ten thousand years.

The chief objection to mixed marriages is the social one. Where a community disapproves of mixed marriages, the children are likely to be at a disadvantage. They may be excluded from recreational, economic and cultural opportunities, or be otherwise socially handicapped. There is also the more immediate difficulty in many cases of disharmony between the parents. For with different training and background, they may not agree as to the right way to do any one of the thousand little things that make up our daily living with others. Such disadvantage, however, is obviously unrelated to questions of race or organic constitution. We may see disasters in families of well-meaning men and women who have not learned how to meet differences in points of view, in temperament, in mannerisms, and in the routine management of affairs. These difficulties arise even where the mates are of the same stock, the same religion, the same political views, but come from different kinds of homes. They arise with the two or three generations of the same family, living in the same house!

Race Superiority The American melting pot has brought into being a population that combines cultural resources from all over the world. Regardless of the motives which sent people from the homes of their ancestors into this new world (and some were forced to come here unwillingly), each has brought with him something of human value. But this mixing of peoples has also raised many new problems. Those who have been occupying a particular portion of the earth for any length of time can hardly help feeling that newcomers are intruders. If these newcomers please us, we are glad to have them stay; but if they annoy us, we may tell them to go back where they came from.

It is easy to forget that we and our ancestors have been here but a short time, perhaps a few generations at the most. And there were others here before us who resented *our* coming. From this point of view, there is no question of right. Primitive people fought it out, and the stronger drove the weaker away or destroyed them. From a broader point of view, however, the human race in its life through the centuries has been made up of many kinds of peoples in constant migration and in constant conflict.

It is largely a matter of chance that you and your family live in one state rather than another, or on this continent rather than another. Nevertheless

we cling to our own—that is, the familiar. And we fear those whom we do not understand. Being intelligent and more or less civilized, we have to make up *good reasons* for our dislikes and our antagonisms. We do, therefore, exactly what very primitive people do: we assert that we are *the* people, and that all others are at best not quite so good. We may base our claim to superiority on almost anything that we have in larger measure than others. It does not matter whether it is tallness or large teeth or big muscles or narrow skulls. Whatever distinguishes us is naturally superior. When we see others claim superiority, their action appears to be childish.

In our own times and in our own country, as well as in many European countries, we have attempted to be more "scientific". We have tried to "prove" by tests and measurements and lists of characteristics that our people are superior. And, properly, we have laid emphasis upon those qualities that distinguish human beings from other species—intelligence, imagination, creative ability in the arts, skills of various kinds. Unfortunately, however, we have neither adequate scales for measuring these qualities nor satisfactory methods of distinguishing native, or inherited, abilities from the effects of culture and tradition. How could you tell, for example, that an Eskimo or a native of New Zealand had a natural aptitude for music or mathematics or mechanics or art appreciation? It would not help us to compare the present accomplishment of a hundred Eskimos of, let us say, twenty years of age with a hundred twenty-year-old Californians or Swedes.

Illiterate Mexicans learn to operate automobiles and to keep them in repair. Ignorant Russian peasants learn to make and to operate huge agricultural tractors and military tanks. Peruvian Indians learn to play European musical instruments and to compose symphonies in the classical form. Descendants of slaves in our own states become distinguished poets, musicians, scientists and mathematicians.

By the way, the four men shown in the illustration on page 519 all claimed to be Irish. A still greater variety could have been selected from among the "Irish" examined by one local draft board during the First World War; and these "types" could be duplicated by Scandinavian Lutherans, Italian Catholics, Scotch Presbyterians, or Russian Jews who came before the same draft board.

In Brief

Some species of organisms have become extinct; new ones have replaced them.

Occasionally individuals that depart decidedly from their ancestral patterns transmit their distinctive qualities to their offspring.

The mutation theory of evolution supposes that natural selection, acting upon sports, or mutations, results in new species.

By applying the theory of mutation and the techniques of breeding, new "artificial" species of plants and animals have been established experimentally.

On the basis of structure and form, on the basis of chemical and functional characteristics, and on the basis of stages in development, human beings are most like monkeys and apes.

The blood of man is more like that of an ape than it is like that of a monkey, and it resembles that of a monkey more than that of a lemur.

From a biological point of view, all human beings are of the same species, notwithstanding the great variations among distinct "races".

As with other species, inbreeding of human beings for many generations appears to establish a fairly uniform type in a given locality.

As in other species, hybridizing among human strains shows no effects that are consistently advantageous or disadvantageous.

EXPLORATIONS AND PROJECTS

To find out about the origin and development of new varieties of vegetable, fruit and crop plants or the recent developments in livestock, investigate among seedsmen, horticulturists, poultrymen, dairymen, breeders of livestock, fanciers, or others who have direct contact with the practical work of improving or multiplying live plants or animals. Report on origins of new types that breed true—whether chance discovery or deliberate creation; methods used, special value or interest, and so on.

If direct information is not accessible, use catalogues, reports of associations, the 1936 and 1937 yearbooks of the United States Department of Agriculture, or other sources. Summarize material to show how principles of heredity have been applied in the development of new species.

QUESTIONS

1 What is the relation of an organism to the germ cells it bears?

2 How did de Vries explain the origin of new species? Upon what facts did he base his explanation? What is there to support his explanation? What are its limitations?

3 What does an individual get from its environment? from its ancestry by inheritance?

4 How do you account for the origin of new species?

5 What evidence is there of man's relatedness to other organisms? To which other groups is man most closely related?

6 In what respects do we consider the origin of the human race like that of other species?

7 What evidence is there that certain races are superior to other races? Why is the evidence inconclusive? What are the social and political implications of the issue?

8 How might the universal use of airplanes and modern science influence our ideas of race superiority?

Something happened. There were no witnesses whom we can question now. No dependable records were made. Is it possible to find out what happened? Can we solve a crime mystery without witnesses or "clues" or records?

Looking into the remote past, we ask questions about beginnings: How did the earth begin? How did life begin? But the answers must be largely speculative. There is no direct evidence. But we cannot help wondering, How *could* it have been? We cannot help guessing. But we must not pretend to *know*—just how the world began, for example, or how life first appeared. Certainly we do not know merely because we have learned what the ancient Assyrians or Egyptians believed. How could those ancients really know?

As in attacking a murder mystery, we can undertake to solve these complex and difficult problems in two quite distinct ways. We can solve the mystery according to the way we feel about the persons or objects involved. We can say, for example, "It must have been the butler, for I do not like his eyes or his hair," or "It couldn't have been the duchess, for she came from our town." In much the same spirit, we can explain night and day, for example, by our need for darkness to sleep in. Or we can say that life could not have evolved, because we do not like to be compared to lobsters or lions.

The other general method starts out by asking, What are the facts? Of course we cannot get the facts about *just what happened.* If we could, there would be no mystery to solve. But there are facts, and we have to get all the facts that bear upon our problem—without prejudice. We might consider, for example, that there are some very nice people with hair or eyes like the butler's, or that even in our town there have been some people who really were not very nice. Or we might consider that day and night are sufficiently explained by observing the movements of the sun around the earth.

As to the origin of life, we have to consider facts about the history of the earth—not what is told by people who remember what they were told—but facts. We must have facts about the contours of the earth's surfaces and about the constant distribution of earth material and waters. We must have facts about the structure of the earth's crust, about the chemistry of the oceans and of soils, about the varieties of life-forms and their distribution. These facts by themselves tell us only what we can see *now.* To form any sensible ideas as to what happened millions of years ago—and even to "believe" that there have been millions of years rather than a few hundred or a few thousand —we have to go a step farther. We have to make up our minds about what we shall *assume* about happenings in general. Do things just happen? Is there any order in the universe that we can discover? Is there any connection between what happened yesterday and what will happen tomorrow? If we assume that anything can happen, that there is no sense, no understandable

connection between events, then facts are of no consequence. And for that matter, the question itself has little meaning. But if we assume that there are relationships among events, and that we can unravel them, then we can begin to use the facts to solve the great mystery—at least in part.

Assuming that there is order in the universe, we attempt to interpret the past by what we can see in the present. What is the connection between plants and animals living today and those that lived last year, a hundred years ago, a thousand years ago, or before people made records? From the bones in graveyards, from the shells in abandoned camp sites of primitive people, from the carvings on ancient temples and paintings in ancient caves, from bones dug out here and there the world over, we make up our answers. There must have been elephants where Paris now stands. And there must have been horses and camels in America long before there were any white men—or any Indians either. The *predecessors* of those elephants and of those horses must have been different. Were those different animals also the *ancestors* of the ones we see today? And did water animals once dwell where now we see the Alps?

Such guesses are logical. But are they plausible? To answer that we seek other facts. How do mountains originate? How are layers of shale and limestone actually formed? How are mountains worn away? What makes the sea salt? How long does it take a river to remove a million tons of earth from the middle of a continent? How fast does sediment build up the ocean bottom?

The most important facts about the origin of life-forms have been discovered since the beginning of the century, although there were good guesses and preliminary scouting and experimenting before. *Species do actually arise from ancestors that were different.* It is not necessary to "believe" that the ancestors of present-day life might have been different. It is almost impossible to believe otherwise if one faces the facts—unless one dislikes the messenger's voice. The facts of heredity, the facts of classification, the facts of development, the facts dug out of the earth's crust and ocean-beds build up an unassailable case for the descent of species from earlier forms, with modification. Incidentally, these facts enable us to produce "artificial" species.

We can do little more than speculate as to the origin of the first living beings. But today speculating on such problems is considered futile unless it suggests theories that we can test experimentally. We are far from making life or from knowing how it came to be. We cannot even define life except as a process, a changing—not as a thing. There is a vast difference between "living matter" and chemical compounds as we know them in the laboratory. Viruses, ferments, vague and almost formless bits suggesting minute bacteria, seem in some ways to fall between the two. Life is certainly not something by itself. It is a process of change inside organisms and also outside them, in the surrounding world—which includes other organisms as well. It is a way stuff behaves, under certain conditions, when it gets started.

UNIT SEVEN

Why Cannot Plants and Animals Live Forever?

1. Are all plants and animals useful to man?
2. Can a plant or animal be injurious to us in one way and useful in another way?
3. Does an animal's instincts always make it behave in a way that is good for getting what it needs or for escaping danger or enemies?
4. Do most plants and animals die a natural death?
5. Is it possible for plants and animals to live without injury to other living things?
6. Could a given region support more life if all animals ate only plants?
7. What causes some pest or some disease to increase rapidly at certain times?
8. What makes epidemics usually stop abruptly?
9. Why has man been called the most destructive of living species?
10. What happens in a region when native plants or animals are driven out of it or exterminated?

We can figure out a complete balance of chemical and physical forces in organisms, like the balance of income and output of an engine. We feel nevertheless that "life" yields something over and above the chemical and physical transformations of matter. As conscious beings, thinking of our pleasures and satisfactions, of our plans and purposes, we wonder sometimes, "Why cannot this go on forever?" Even in moments of suffering and sorrow or of disappointment, we hope and reach out for better days. We cling to life and we want more. Life is good. Why must it end? From what we observe in other species, we assume that there is in all organisms a constant urge to keep on. Presumably life is "worth living" wherever it is possible. But to the extent that we are *aware* of life satisfactions, and especially of life possibilities, we are puzzled and disturbed by the limitations. We recognize, of course, that in nature nothing endures "forever". Natural objects are combinations of other objects or bits. And these *combinations* are constantly being broken; the parts are constantly being rearranged; the balance is constantly being upset. Wherever anything is going on, any action whatever, all objects change; the very mountains and the planets change. And to live means above all to do, to rearrange.

Life in general goes on, then. But individual plants and animals come and go—some more quickly across the stage, some more slowly. And at any given moment, in any particular spot, life goes on at all only as some individual succumbs and yields its body to others as food or as raw material. And even-

tually each returns the very molecules and atoms of its constitution to the air and the waters, and to the earth, from which its substance came.

It is impossible for every new individual to live out the full cycle typical of his species. A single pair of frogs may produce thousands of eggs in a given season. From a single pair of houseflies starting out in the spring would come enough progeny by the end of the season—*if* all lived and grew and reproduced—to fill a space as large as a city block to a height of six or seven stories. Essentially there is the same disproportion between the new admissions and life opportunity for every species—even the slowest growing and the least fertile.

There is not only a limited amount of space. We may imagine that as species become more differentiated, many will fill in unoccupied spaces and so increase the total amount of living matter in the world. There is, however, a definite limit to the total amount of carbon, hydrogen, sulfur, nitrogen, phosphorus, and so on. And only a limited fraction of these essential elements can be embodied in living organisms at any time. For plants and animals are "alive" only while the material is actually shifting from the nonliving world into the living, from organism to organism, from the organism outward.

All species are, in fact, closely interrelated through their living processes. Not only do they come into conflict for limited space, light, water, air, the earth elements; but no species could thrive if the others died out, for the various forms of life depend upon one another. Living means dealing with the inanimate world, but it also means dealing with other organisms, directly or indirectly. There is but little chance to continue indefinitely the life of individuals; more abundant life seems to be a matter of adjusting the interdependent and the conflicting elements for a balanced total. This balance among all living things is itself a constant rise and fall, a constant coming and going, a constant give and take. Like the waves of the sea, which endlessly take on similar shapes and yet are never for two moments the same, life is a continuous balancing and adjusting rather than a crystallized and finished fact.

1. What things must organisms have to live?
2. Do all living organisms have to have the same things?
3. Why do organisms get old?
4. Why do some species live so much longer than others? Why do some individuals of the same species live so much longer than others?
5. Is it conceivable that man may sometime be able to live forever?
6. What environmental factors limit life?
7. Why can some animals live only in the tropics, while others live only in the arctic?
8. Do desert plants grow better if kept dry?
9. How do organisms spread from place to place?
10. Why is it that we do not find two species of large cats living in the same region?

Living things act as if they were driven from within to keep on living. The drive for food, with its thousands of marvelous adjustments, often involves violence or stealth. But these are matched by the violence and stealth through which organisms protect themselves against the food-seekers. Both food-getting and resistance to food-getting—by others—are essential parts of that self-preservation which has been called "nature's first law".

This drive to live encounters continuous changes in conditions—night and day, hot and cold, changing moisture and minerals and air. It also pushes off the inevitable end of individual life. The drive to live involves reproduction and replacement. And life moves through space, pushing outward in all directions, from every established individual plant, from every group of animals.

What factors or native qualities favor particular species? What are the factors which limit the increase and spread of a species? Why is the total life in a place greater at one time than at another? What part has man played in modifying the distribution of life on the earth?

Is Death a Natural Process?

Life Is Self-limiting In all plants and animals metabolism depends upon certain external conditions. The intensity of light, for example, influences the rate of photosynthesis or the rate of growth. At one temperature metabolism in a particular kind of organism proceeds at the highest rate; at another temperature it ceases altogether. But even if each special condition were at some point most favorable to absorption, assimilation, oxidation,

contraction, excretion, and so on, metabolism could not remain constant; it cannot just "keep on".

For being alive means something more than the sum of all these processes which we observe in organisms. Each detail of action depends not only upon the outside conditions; it depends upon *all the other processes*. And the relationships among these processes are always changing. Assimilation, for example, depends upon absorption. The rate of oxidation depends upon the temperature as well as upon supplies of oxygen and of fuel. Metabolism depends further upon the removal of wastes, but this in turn depends upon the relative concentration of substances inside the cell and outside it. No process goes on by itself.

Even in so simple an organism as a bacterium, the processes cannot continue uniformly, although the food supply, the water, and the temperature may "remain the same" for a long period. For, as the cell grows in size, the surface through which it absorbs and excretes enlarges more slowly than the mass of protoplasm (see illustration, p. 345). The supply of food therefore steadily diminishes for each unit of protoplasm, and excretion becomes slower and slower. Sooner or later, then, every cell must stop growing. This is not the only feature about living cells that sets a limit to indefinite growth, but it suggests how a process may limit itself.

Under conditions favorable to growth, a particular kind of cell—a bacterium, for example—divides into two when it reaches a certain size. The mother cell goes out of existence. It has not *died*, for the protoplasm of which it consisted continues alive and active; but it no longer exists.

Life Is a Pattern The external factors upon which living things depend are not always uniform. But even where they are fairly constant (as deep in the ocean or inside a warm-blooded host) each individual, each cell, has its definite pattern of growth. In each species the individual grows and develops, from stage to stage, in a relatively fixed or consistent pattern. Every stage of life leads automatically to the next. And in most species this succession leads to a "natural death". If we measure the intensity of metabolism by cell division or by growth, we find a general slowing down. As the zygote starts to grow, it doubles its weight several times in the first few days. A human baby doubles its weight in the first six months after birth. Each year it adds a smaller fraction of its weight, until growth becomes at last negligible.

One cannot, by taking thought, add to his stature. Neither can one turn back his developing, nor skip a stage, nor dally indefinitely along a pleasant stretch. It is no wonder that men, reflecting upon life, have been impressed with the idea of "fate"—which compels everything to happen in its appointed time, everything to happen in its preordained spot in the great procession.

What Causes Death? In spite of this picture of an irresistible and irreversible march of events, life is anything but uniform. Individuals differ in

the pattern of development. Among human beings, for example, we differ as to the time when the first teeth appear, or the last teeth. We differ as to the age at which we begin to walk or to talk, as to the time at which we mature, and as to how long we remain at each stage. And especially do we differ as to how long we postpone the end of individual existence. In addition to having such inherited differences, the individual's pattern of development is frequently altered and blocked. Yet it has been difficult to find out what brings about "natural death". One reason is that very few human beings die a "natural death". There have been many theories regarding the chemical and physical changes which lead to death, where no injuries have taken place.

August Weismann, already mentioned as the author of the "germ plasm" idea (see page 507), pointed out that the protozoa (and one-celled plants too) are *potentially immortal.* In this way he emphasized the idea that under suitable conditions a line of such simple protoplasm can remain alive indefinitely through successive cell-divisions. There is no natural death in these species, as we have seen.

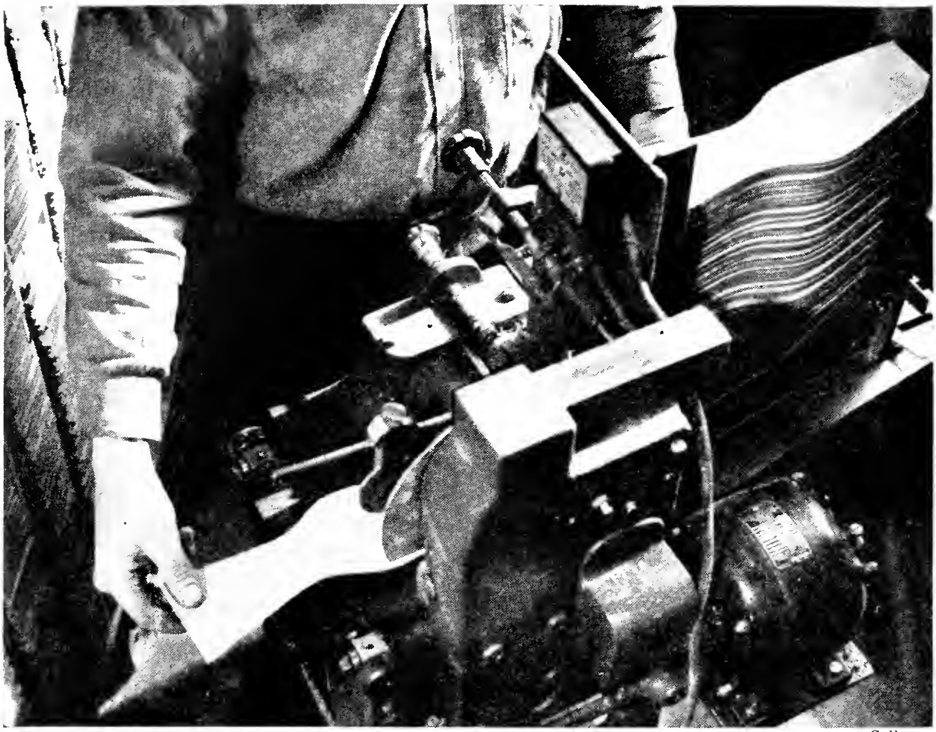
In the more complex many-celled species the germ plasm may continue indefinitely, so long as reproduction takes place. The individual body, or *soma*, however, which we conceive to be an offshoot of the germ plasm, may have a limited duration, except where there is vegetative propagation (see illustration, p. 508).

According to this view, life became "mortal" when it acquired a many-celled body, in which *germ* cells are differentiated from *soma*, or body, cells. But we must not confuse the idea that "protoplasm continues to live" with the idea that a particular "individual" or person continues to live. Even in the case of the ameba or paramecium the life of the individual has a definite limit.

What Are the Advantages of Specialization?

Division of Labor We can see the advantages of "physiological" division of labor from our experience with social or economic division of labor. In fact, we are so familiar with specialized organs carrying on specialized functions that we find it in some ways more difficult to understand a "simple" system, like a bacterium, than a complex one, like a human body.

Imagine the life of, say, a dozen scattered human beings roaming over several square miles, each one living by himself. Compare these with a group or family of the same number living together. In the simplest of human societies, where there is only a family group, division of labor is already present. The men hunt while the women look after the children and prepare food and shelter. Members too old to take part in the strains and dangers of hunting keep weapons in repair or make new ones. Children too young to do more difficult work can fetch and carry for the older members, saving the time of



Galloway

ADVANTAGES OF SPECIALIZATION

Ten persons can do ten times as much as one person on an average. If we break the task into ten jobs for a crew of ten workers, they can easily double their average output. If we break each job down so that it takes the work of, say, 30 or 40 persons to complete the task, the crew will multiply its average output still further. What are the sources of the additional production?

the latter. Such co-operation, or teamwork, enables the group to use to best advantage the efforts of the more able, for these can avoid the light or simple tasks, which children can do just as well. And it enables the less capable to make fuller use of their skills and energies than they could if they lived by themselves.

The net result of such co-ordination of specialized functions is not only a larger total amount of living effort, but surpluses of food and time that increase the total satisfactions. Organic specialization, like social specialization, makes possible a more *efficient* use of materials and energies, and it makes living possible under new conditions. As we have seen, almost everything that distinguishes one level of plant or animal life from the levels below is an adjustment to new conditions of living (see page 386). Specialization has added to the total of life.

Galloway

DISADVANTAGES OF SPECIALIZATION

The grower who specializes in cotton finds himself out of work until the market catches up with the cotton in stores and warehouses and factories. In the meantime, he cannot eat his cotton

Advantages of Specialization[1] In our society such surplus production enables some people to give all their time to making music, or painting pictures, or dreaming up poetry and plays and amusements for the rest of us. It enables more and more men and women to follow their hobbies, and in many cases to make careers of their hobbies—as in the arts or scientific research or play-acting or professional athletics or doing stunts of all kinds. That is to say, specialization has made possible more specialization. We do not all have to dig and saw wood and fetch water, because our potatoes and fuel and water can be supplied by relatively few but highly expert specialists. As a result, all of us have more time to play, and some of us can enrich the playing of all.

Disadvantages of Specialization In the individual organism, as in social life, excessive specialization may bring its disadvantages. When an earthworm is cut in half, the less specialized segments near the middle produce new growth and replace the differentiated head and tail. Among vertebrates serious injury to the more highly specialized organs, such as the heart, the liver,

[1]See No. 1, p. 538.

the kidneys, or the brain, destroys the life of the whole. Animals in general have carried extreme specialization much farther than plants; but in many plants the more specialized structures, such as flowers, cannot be regenerated.

Excessive specialization has the further disadvantage that it requires more complete co-ordination, as in the endocrine and nervous systems of human beings, for example. In society "each minding his own business" makes no sense. There is no point in turning valves, pulling switches, pushing buttons, grinding tools, mixing paint or dough, firing ovens, or pumping water except as each special task is related to a common plan. Water comes out of the faucet not merely because you turn the spigot, but because thousands of men and women whom you will never see have been for years doing their thousands of separate jobs, all planned to place water under pressure behind your valve.

In the organism, chewing food concerns more than the face. Pumping blood and secreting bile are not carried on "for their own sakes". Nor is it the eye that "enjoys" the scenery. In such complex organisms as man extreme specialization carries the risk of upsetting the balance, or unity, of the organism through a relatively slight injury to a very small part. This is probably one reason why "functional disorders" and "queerness" are more prevalent among human beings than among other forms of life.

Balanced Functions[1] A person who weighs 118 pounds is heavier after each meal, and loses weight before the next one. In a complex organism like a mammal there is constant alternation of piling up and using up. That is true for life in general and for human populations. We accumulate great stores of food and fibers and other products of plant and animal life during the summer, and then use up the reserve during the winter. The *balance* is not a state of rest, like the sides of a scale that are perfectly level. It is a moving and fluctuating condition in which a swinging in one direction balances that in the opposite, it is a process, it takes time. There must be *over*-production to balance the periods when consumption exceeds production; the problem is that of maintaining the balance.

In a primitive economy human beings depend upon their own skills to get them what they need directly from nature. They are thus largely at the mercy of the weather and other changing conditions which influence the abundance of plant and animal life. In our economy of highly specialized functions not only do we store seasonal surpluses for long periods, but we transport food and other materials from regions in which they are plentiful to regions in which they do not occur at all. On the other hand, our economy has been characterized by ups and downs that appear unrelated to the actual abundance of needed food or clothing or building material. During so-called business depressions of the past people spoke of "overproduction" as if a surplus of materials could explain widespread hunger and privation.

[1]See No. 2, p. 538.

From a biological point of view, it is of course meaningless to speak of overproduction so long as any portion of the population continues to be in want. There might be at worst an *unbalanced* production, so that efforts which should have gone into the making of shoes, for example, went into a surplus of fiddlesticks. Whatever the details in such a crisis, a living system appears to be thrown out of joint not because of any failure in the environment or in the specialized functions, but because each member minded his own business without regard to the relative amounts of his products that were needed. We can see this if we compare the situation to that of a self-contained family that produces what it needs with little regard to what others do, or fail to do. Normally, satisfactory living was obstructed by shortages rather than by surpluses. The important point for society as for the organism is *balanced* production, distribution and use.

It is not only the loss or injury of a specialized organ that may handicap the whole organism, but also the overgrowth or excessive development of some part. Such overgrowth or overfunction threatens the wholeness, or the *balance*, of the body, particularly when it affects the nervous or the gland system. In plants and animals too there may be faulty co-ordination, or unbalanced functions, interfering with continued growth or development.

If there is an overgrowth of some tissue, an enlarged thyroid, for example, or a tumor, the surgeon may remove the surplus and restore the balance of the organism's functions. We cannot so easily cut out superfluous farmers or brokers or harness-makers. The distress which comes from disturbances in the *proportions* of various functional or occupational groups suggests the disadvantages of overspecialization in society. But in time of war or of great natural disaster, brokers and harness-makers can take on other functions.

What Are the Physical Limitations on Total Life?

Limitations in the Environment[1] As we have seen, the adults of almost any species would produce enough offspring to fill the earth or the ocean in a relatively short time *if* all the eggs or seeds reached maturity, and *if* all individuals reproduced at the average rate. From the very nature of life, however, there are in every case too many requirements that cannot be met. Few individuals in any species actually go through the entire cycle of growth and development. What determines which ones are destroyed along the road, and which ones will actually reach the end of the journey? Of a thousand persons born at about the same time, the number living diminishes gradually until none remain after about 100 years.

The exceptional survival record of our population is possible, of course, only because we have been able to obtain abundant food and to avoid various

[1]See No. 3, p. 538.

illnesses—able, that is, to restrict the lives of other species. For we know that growing and developing and reproducing are possible for some individuals only on condition that other living things are destroyed; here too life is self-limiting. Now the destruction is going on all the time, just as the production of new protoplasm—and new individuals—is going on all the time. Making of new is limited by destroying of old. Just as the growing body carries on by oxidizing parts of its own protoplasm, life in general continues as individuals die and are replaced by others.

The Life-and-Death Cycle Since there must be a limit to the various kinds of elements, and since plants and animals make use of the materials in the earth and the air and the waters, will not these materials at last become exhausted? And would not that mean the end of all life?

The plants and animals in a restricted area, such as a farm, might live for several years without the need for replacing what they removed from the soil. But as the products of a farm are normally carried off to be used elsewhere, the soil must in time be deprived of certain elements essential to further life. But what happens in a balanced aquarium, in which the carbon dioxide exhaled by the animals is converted by the green plants into food used by the animals, and in which the animals are supplied with oxygen?

In addition to the balance of carbon and oxygen, the living organisms in this restricted area must have a supply of the materials that become permanent parts of the protoplasm—nitrogen and certain salts. The nitrogen also circulates through the organisms, the soil, and the water, as we have seen (see pages 151, 152). But some of the inorganic material remains largely within the living bodies until they die.

When we consider life in general, maintaining a succession of living things appears to depend upon the circulation of materials. There is no danger that all life will come to an end merely because the materials may become exhausted. The same materials enter into a constant succession of new living things. The chain is endless because it includes the remains of plants and animals that have died. The materials, instead of being "locked up" in bodies, whether living or dead, pass on into other cells, other plants and animals. Each particle in the course of years becomes part of many different organisms, of many different kinds (see illustrations, pp. 151 and 153).

How Can Man Regulate Population for His Purposes?

Distribution of Life[1] In the world as a whole there are about 2000 million human beings. If we should spread out evenly over the land surface, we should be about 33 to each square mile. That would give us plenty of elbowroom. But a very large fraction of us would soon die. For millions of those

[1]See No. 4, p. 538.

square miles are barren mountains, jungles, and swamps, and vast stretches of desert that can support very little life of any kind and no human life at all.

As we know, the density of human life varies from one region to another. But most of us would be astonished to learn how great the variation actually is. For Australia the population averages a little over 2 to the square mile; in Alaska it is 1 to 10 square miles; in Japan it is over 400 to one square mile. In both China and India there is so much desert and mountain area that the ratio of people to *total* area is very misleading—something over 100 per square mile for China and about 180 per square mile for India. Similarly, the average distribution for Egypt is about the same as that for the United States—under 40 per square mile. But if we consider the regions actually occupied, the density of Egypt's population rises to over 1000 per square mile.

Europe is the most densely populated continent, and Belgium the most densely populated country in Europe, having 635 to the square mile, as against 482 for Great Britain. If we consider England and Wales separately, however, the density is about 650. This comparison suggests many questions about the distribution of human life in general and about the concentration of life in particular regions.

The earliest concentrations of human population were along the shores and rivers, then in fertile regions that supplied game as well as fish, and eventually on soil suitable for grazing cattle and for raising crops. Cities became possible only when division of labor had gone far enough. For it takes trade and traffic to bring together from over a wide area the needed food and raw materials that city dwellers cannot produce themselves. The large industrial centers, which in modern times have become the most highly crowded areas, could not support life abundantly except through extensive intercourse with other communities.

Distribution Automatic If we all tried to live at the seashore, the total amount of human life would be but a fraction of what it actually is. Through thousands of years the human population of the earth probably increased very slowly. For aside from all other considerations, there is a limit to the number of persons who can find a livelihood on the seashore or in any other specialized environment. It became possible for the race to increase in numbers only as it came to live *in a great variety of environments.* In modern times a rapid increase in human population had to wait until we knew enough biology to control (1) many species of plants and animals that yield food and other useful materials, and (2) those other species that interfere with our health and other interests.

The distribution, or spread, of a species away from a center is influenced by the pressure of population and by the conditions in the new regions. But the limiting factors always include *other species*, as well as the physical conditions.

WHAT KEEPS A SPECIES FROM SPREADING

The distribution of a species away from a center is influenced by the pressure of population and by the physical conditions in surrounding regions. But the limiting factors always include other species — possible food, possible enemies — as well as soil and climate

Hindrances to Human Life[1] Human population can increase only where the soil and the climate are suitable for those species that we depend upon for food and for other materials. But suitable soil and climate are not enough to make a region secure for human habitation. Other animals and plants may have established themselves ahead of us, and they may succeed in keeping us out. Breaking new territory has often meant fighting wild animals and driving out inhabitants already there. When early settlers cleared forests to make their homes and farms, they removed not only trees, but a vast amount of animal life—birds, mammals large and small, insects of many species. And they created conditions in which many species of plants could no longer keep going.

The expansion of human population would seem to be a simple problem of replacing the native population with cultivated plants and domestic animals. When this process was repeated over and over again, and more and more rapidly, other things began to happen. Sometimes the attempts to cultivate crops in a new region succeed from the first: the soil and the climate happen to be right. Sometimes a species succeeds even better than it did in the old home from which the settlers came, for the insect pests or the parasitic fungi of the old home were not brought along. In other cases, however, the best

[1]See No. 5, p. 538.

knowledge and skill fail to make such efforts go. There are new enemies never encountered before. In their attempts to penetrate tropical regions, Europeans have been for several centuries obstructed by the new kinds of diseases and pests. Where many different plant and animal species have become established, man's arrival often interferes with conditions seriously. We sometimes destroy what we should like to preserve, or else increase forms that we find objectionable.

We have already seen that many of our cultivated plants depend for completing their life cycles upon the co-operation of certain insects (see page 408). Other cultivated plants are destroyed by other insects. To preserve and multiply our plant and animal populations, we have to look after many other species—encourage some and destroy others. To ensure a human population, it is not enough to establish physical and chemical conditions that favor cultivated plants and animals. We need further to guard against bacteria, protozoa and worms that cause disease, and against mosquitoes, fleas, flies, various rodents and other carriers of infection.

To make the earth support more human beings, it becomes necessary to control the distribution and the density of hundreds of other species—some of them directly useful, of course, but others important in various indirect ways. Some affect the health of humans and of our cultivated organisms. Some supply food for our cattle and other domestic animals. Some affect the physical conditions in ways that are important. No man can live by himself alone; but it seems that no other species can live by itself alone.

In Brief

Life is self-limiting and in every cell there is an orderly succession of stages from beginning to end.

Among simple organisms a line of protoplasm can remain alive indefinitely, whereas in the more complex, many-celled body it cannot.

As in social organization, organic specialization makes it possible to use available materials and energies more efficiently and to carry on life under new conditions.

Increased specialization involves a more complete and more delicate coordination, which is accompanied by a lessened capacity of the parts to regenerate and to adjust themselves.

Growing and developing and reproducing are possible for some individuals only on condition that other living things are destroyed.

A species increases in numbers as favorable conditions arise, or as it moves into favorable environments; man goes further and increases in numbers as he finds ways of adjusting a great variety of environments to his needs.

Materials released from organisms, living and dead, pass on into others, each particle in the course of years having been part of many organisms.

Where a balance has been established through the interaction of many different plant and animal species, intruding man often disturbs existing relationships by destroying what he would like to preserve or by increasing forms that he considers objectionable.

EXPLORATIONS AND PROJECTS

1 To investigate certain advantages and disadvantages of specialization, compare the relative effectiveness with which different species of plants and animals carry on particular functions. For example, we might compare earthworms with caterpillars and with adult insects as to the speed and effectiveness of locomotion, the manner of food-getting, and recovery or regeneration after injury. Compare structures and living habits of various parasites of birds and mammals and of the dodder, a common parasite of clover. Relate the characteristic stages and specialized structures to the mode of life. Show wherein specialization is an advantage; a disadvantage.

2 To investigate the physical conditions involved in certain plant associations, visit a neighboring woodland and compare the growth on different slopes, on different soils, and under different moisture conditions. Note the relative heights of the trees, the kinds of trees growing, the density of the shade, the number of species, the luxuriance of the growth, the dominant forms, the presence of simple pioneer plants, and any differences in the kinds of animal life found in the various plant associations. Summarize the results of observations by relating the various physical conditions to the kinds of plant associations found.

3 To find the relation of crowding upon growth, plant seeds of a rapidly growing plant very close together in one pot, and widely separated in a second pot. Maintain optimal growth conditions in both pots for several weeks and compare results. Account for differences in terms of physical conditions that limit development.

4 To investigate the problems associated with a shifting population, find out how the population of the United States is distributed and how this population has shifted during the past seventy or eighty years; relate these shifts to conditions that brought them about and to their effects upon economic resources and developments.[1] Construct a large map showing present centers of population; list the chief areas in which population is centered; indicate on the map or on the lists or on both the chief contributions to human life in each area.

5 Report on population shifts resulting from the development of a new industry, from the discovery of mineral resources, from changes in the soil or in the water supply, from the emergency needs of the Second World War, or from the introduction of better means of transportation, as railroads, highways, or air fields.

[1]Refer for information to the National Resources Committee report *The Problems of a Changing Population*, May, 1938, or to an atlas or to a geography.

1 In what different ways is the total amount of life at any given time or place limited by the physical environment?

2 What conditions bring about an increase in the numbers of any species of plant or animal, including man? a decrease in numbers?

3 In what ways are the numbers of individuals of one species in a given region limited by other species?

4 How can we show that the activity of one part of the body depends upon that of another? or that it may interfere with the full activity of another part?

5 What advantages come to a living thing through the division of labor among organs and tissues? What disadvantages?

6 What are the conditions for a high degree of division of labor among human beings? among different nations?

7 What usually happens to a natural community when man arrives on the scene?

8 To what extent can man control the numbers of other living things in any given region? the numbers of his own race?

9 How are post-war conditions likely to influence the distribution of populations?

1 Do any plants fight in the way that animals fight?
2 Do any species ever die out in nature?
3 How can we tell whether animals which are new to us are useful, or harmful?
4 How do animals know their enemies instinctively?
5 If species result from adaptation to particular conditions, how can they live in strange surroundings?
6 Do animals ever kill for any reason except to get food or to protect themselves?
7 Do animals ever kill others of their own species?
8 Is it possible to avoid competition?
9 Are the survivors in a conflict always superior?
10 Would there really be room for all the persons who are born?

Life is always interfering with things, always rearranging things. It will not let things remain as they have always been. That is why people have thought of life as a kind of "force". It is like rushing water, changing the face of the earth. It is like a storm, stirring everything up. It is like raging fire, destroying what it touches. Yes, life is like all these "forces". But it differs from them all, too.

It is more helpful to think of life as unique, in a class by itself—not as a something, not even as a force. Life is what living things—all organisms—do in common. It is a persistent enlarging and extending of itself in all directions, a grasping of the outer world, a converting of the outer world to itself.

But the world seems unwilling to be taken in that way. Everything is always interfering with life. This life process constantly meets resistance. Especially is there resistance and interference from parts of the world that are really playing the same game—that is, other living things. There is resistance, and sometimes a fighting back. Life is a struggle, not a flowing along, not a one-sided action. It is interaction, a give and take with the entire environment, including other life.

How Can We Say that Plants Struggle?

Passive Struggles[1] We have learned to think of the activities of common plants as rather quiet processes of osmosis, diffusion of gases, chemical change, as in photosynthesis, or very slow—and "cold"—oxidation. What is there here to suggest a struggle? If water is abundant in the soil, the roots will absorb it rather quickly—as an old rag might. But if the atmosphere is

[1]See No. 1, p. 557.

saturated, so that water does not quickly evaporate from the surfaces, absorption from the soil may be stopped.

If soil minerals are present in certain proportions, or concentrations, the plant absorbs accordingly. But if there is too little, then the plant absorbs and discharges more gallons of water for every grain of salt. Or if there is too much salt, the flow through the root cells is outward instead of inward. Plants living in salt marshes are in many ways like desert plants, absorbing water against great resistance, or drying up!

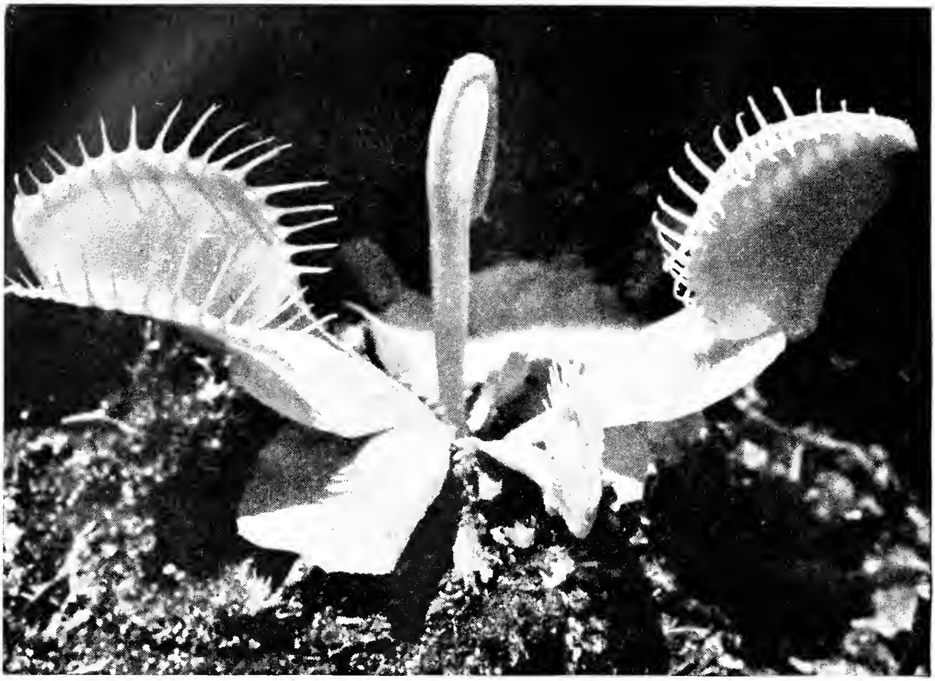
With changes in temperature, most plants continue their metabolic activities more rapidly or more slowly. But sudden or extreme changes stop metabolism. And temperature affects also evaporation, or transpiration. Changes in illumination also alter the metabolism, especially photosynthesis, and the rates of growth of the various parts.

Such variations in conditions influence plants, but they do not, as a rule, bring out any striking reactions. Plants seem obliged to take what happens as it comes, since they are not able to run away, or dodge, or hit back. Here, then, the "struggle" is between a particular organism and changes in the surroundings. The particular organism, which seems to us rather passive, does not really remain as it is very long. A plant does move, if less slowly than most animals. It responds to stimulation or to changing conditions by moving—so slowly in most cases that we have to take special pains to see what happens.

Plants Are Sensitive and Active[1] The simplest evidence that plants are more or less sensitive we may see in the destruction that results from some external change. A plant may be poisoned or overheated or chilled. If the changes are not too severe, however, the plant behaves in ways that, on the whole, protect it from injury. Tropisms (see page 256) on the whole prevent injury, or they increase the likelihood of getting needed supplies. Some plants can capture animal food, in the form of small insects (see illustration, p. 542). Some reduce the exposed surfaces when disturbed by too much sunshine, as the eucalyptus tree. Some close down in the dark, as the clover or sorrel. And very many drop their leaves in the autumn, apparently in response to a shortage of water.

Generally speaking, however, plants respond to external changes very mildly compared with familiar animals. The success of the individual plant in living through a season of changes seems to depend very largely upon the structures and qualities that it develops from the time it starts out as a sprouting seed. Continuing to live depends upon the kind of skin and bark or spines that it grows, or upon the kind of conducting and mechanical tissues it develops, or upon the delicacy and efficiency of its food-making equipment and its food-storing mechanism. And the success of the species depends upon

[1]See No. 2, p. 558.


Rutherford Platt

THE CARNIVOROUS PLANT VENUS'S FLYTRAP, DIONAEA MUSCIPULA

The trap at the tip of the leaf consists of two parts that come together like the halves of an open book when an insect touches against one of the three trigger hairs on the inner surface of each flap. The sections come together rather quickly; curved bristles around the edge prevent the escape of the insect

producing so many seeds that some at least are likely to alight where they can establish themselves, and that one or two at least are likely to reach maturity.

How Plants Compete[1] Struggle commonly suggests our own experience of competition and conflict with other members of our species. But most life activities are not conflicts or rivalries in that sense. Nevertheless plants do "compete". Thousands of plants get started in a garden or field, for example, where only a few can find water and salts—and space—to grow up.

Seeds can get started even while they almost touch one another. For the time being there is room for all, water for all, air for all. And each has its own food reserves to last for a few to many days. But in a few days many of them have germinated. Almost hour by hour others put out their first sprouts—usually the hypocotyl or root-tip. Now they begin to crowd. For after having absorbed enough water to start the sprouting, each is several times as large as it was in the dry state. The crowding raises some away from the soil. And when these lose their touch with mother earth, the tip of the sprout

[1]See Nos. 3 and 4, p. 558.

dries; and that's that. Those more favorably situated begin to dig in. Some act faster than others. The faster ones get the water and send their shoots up before the slower ones get a firm grip on the soil. And as the earlier ones keep on growing and absorbing, the lead becomes greater and greater. The struggle for limited quantities of minerals is similar. And the parts that are aboveground, which soon turn green, have to grow fast enough to catch the sunshine before they are outgrown and shaded by other individuals.

We have already seen that where many different species are present in an area, their specializations usually make possible a larger total population than a single species could maintain. Because species differ in height, in spread of leaves, in depth of roots, in rate of absorption, and so on, several different species fill the area more nearly completely. Nevertheless even different species may compete for the things that they all need, especially water, minerals, and a place in the sun. The competition among the plants is, at any rate, real, even if the struggle does not involve violence.

Pure Chance Each individual seed or plant has a very narrow range of action, and no ability to make decisions or choices. Accordingly, mere chance plays a large role in the lives of plants. The inherited capacities of this tiny sleeping baby plant inside a seed have no relation to where it will alight—whether upon a dry surface or on a moist one, on a bit of fertile soil or on a barren spot. If it never gets to first base, there can be no reproach. Nobody can say that it lacks any of the virtues which are proper to members of its species. It simply had no chance at all. Seeds that get a start and send their roots down may be stopped by a flock of birds or insects, which destroy every scrap of organic matter big enough to grab. These animals destroy the "good" individuals along with the "bad" ones—as would a flood or a fire or a complete drought. We can see why it is that of the thousands and thousands of individual seeds which a mature plant produces, only a very few will in turn reach maturity and reproduce themselves.

How great the role mere chance can play is suggested by comparing the survival rates among human beings. Out of a thousand babies born, some will die almost immediately because of *defective* organs or functions—breathing, digestion, circulation, temperature adjustment, or whatever. In the course of the first year others will die for various reasons—*failure* of the organism at some point *to meet the conditions* of nutrition or excretion or infection or changing temperature. But the number of such failures is probably small. For among different peoples, or among different sections of the same population, the infant death rate varies from about 30 to about 300 per thousand (see illustration, p. 545).

This great variation has been used to argue that some stocks are "inferior" to others. But if we accept this, we must account for the further fact that in the course of time the rates decline more for the "inferior" stocks than for

the "superior" ones. Perfectly helpless babies of any "race" will survive the first year only under the suitable care of elders. That is, the survival rate depends more upon the care and protection that babies receive than upon individual variation in the capacity to carry on as organisms—after the early difficulties are overcome. A poor home will destroy the promising and the worthless in about the same proportions.

The struggle of plants is against enemies, against competitors, against changing physical and chemical conditions. All but a very few individuals are likely to be destroyed in the course of a season, without regard to the particular qualities which might be of advantage in the "struggle for existence".

What Is Meant by the Struggle for Existence?

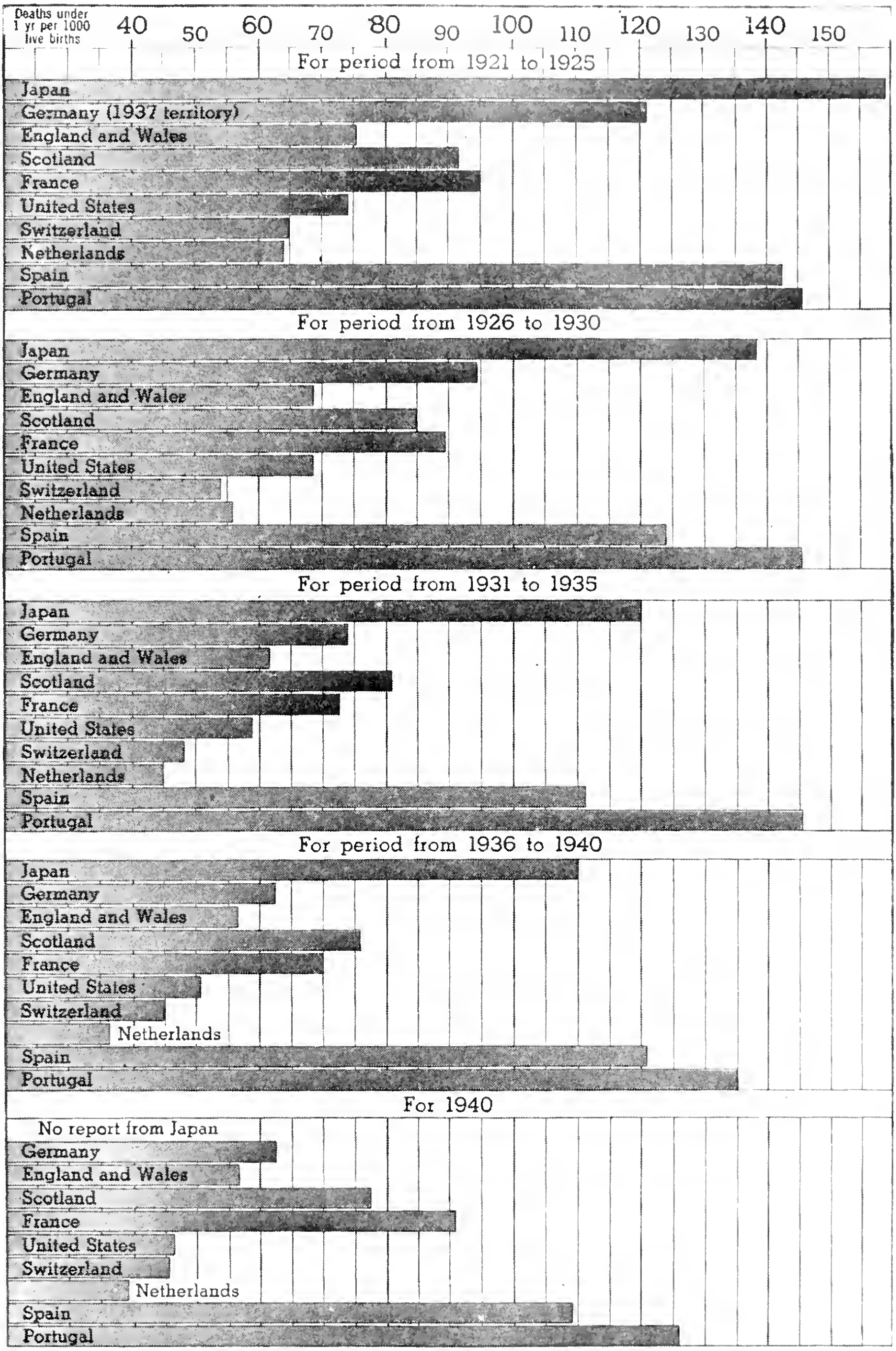
One in a Thousand Some species can keep alive only if each adult (or pair of adults) bears many thousands of new individuals—eggs or seeds. The early stages are subject to frost and drought. And since they contain concentrated food material, they are exposed also to hungry plants and animals of many kinds. A little later the young are still exposed to changing conditions of moisture, temperature, light—and hungry hordes of other enemies.

From one spot to another on the surface, in the soil, in a pond or in the ocean, the physical conditions vary. Here it is colder, and there warmer. Here the concentration of carbon dioxide is high; there it is low. Here there is an excess of one kind of salt, and a shortage of another; but there the conditions are just the reverse. These variations mean that one organism can live here, but not there; that this one can live here, but not another.

Other features also vary. At some points the moisture varies tremendously from season to season, perhaps even from day to day or hour to hour. At another point the nights are very cold and the days very hot. At tide level this spot is well covered with sea water for hours at a stretch, but later it is almost dry and exposed to the glaring sunlight. A living plant or animal may get a start at some point, but be constantly threatened not alone by "enemies", but by the fluctuations in physical conditions. The urge of each organism to get food and to meet the various threats and dangers results in a complex process which has been called the "struggle for existence".

Among human beings the "struggle for existence" is in part a struggle of intelligence and understanding rather than one of swift movements or tough skin or powerful muscles. For the bulk of the human race, infants seem to survive in larger or in smaller proportions according to the kinds of families or civilizations they are born into (see charts on opposite page and on page 547).

This struggle includes many processes that are in themselves rather mild or even passive—like the growing of a shell by the clam, or the growing of a



THE RELATIVE FITNESS OF DIFFERENT PEOPLES AS MEASURED BY INFANT DEATH RATES

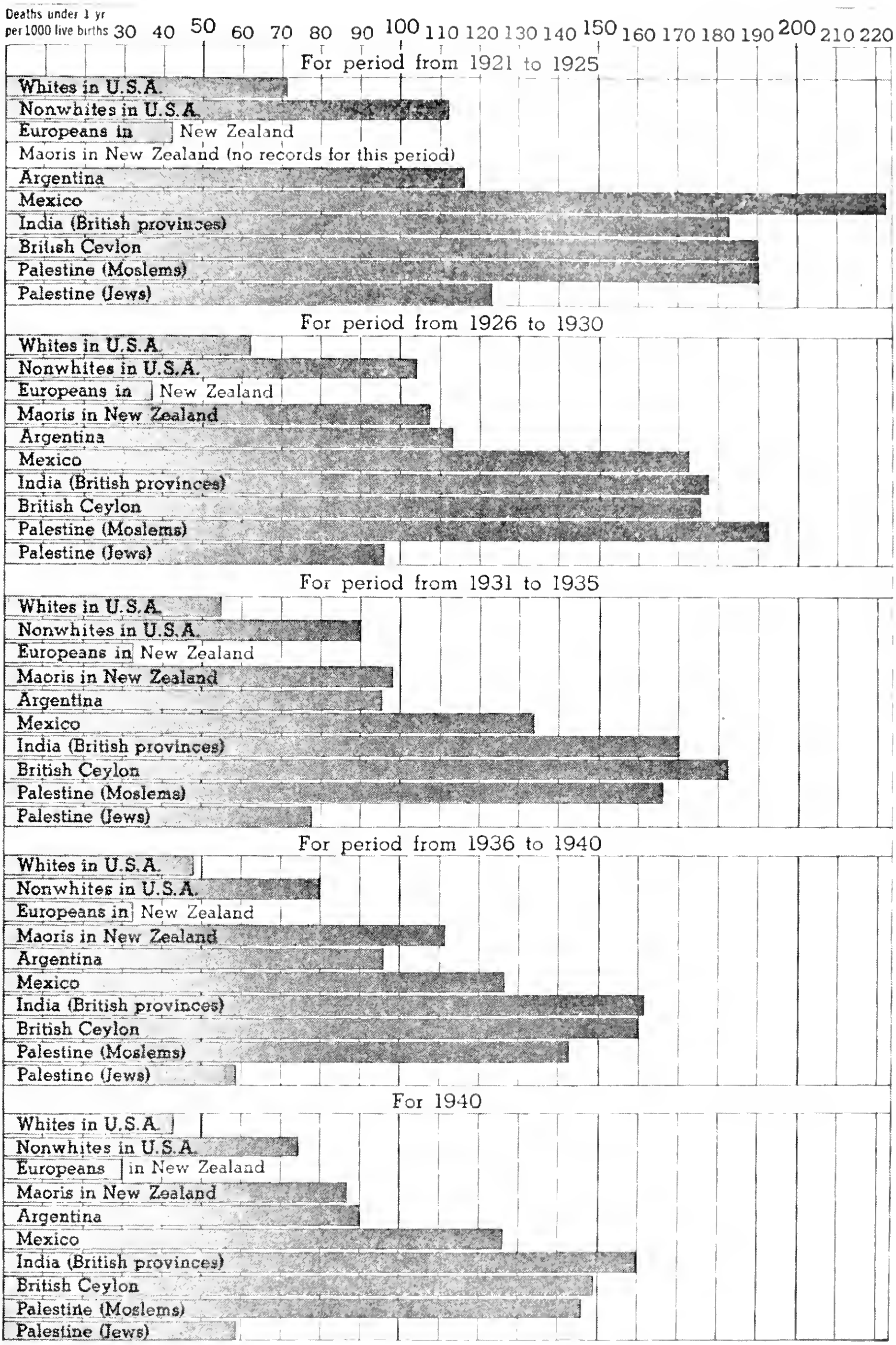
long taproot by the radish, or the dropping of leaves in the autumn. The struggle is a continuous activity at every stage of life. It is an overcoming of obstacles and resistances which arise from the changing environment and from the activities of other living things. It goes on even where there are no enemies or rivals, and even where the needed food, water, air and minerals are abundant. Life is itself aggressive, and all its processes are attacks upon the outer world—or resistance to attacks from that outer world.

The Meaning of Fitness From the fact that more individuals are born than can possibly survive comes the pressure of population. Only a small fraction of those born will live long enough to reproduce themselves. But which one will die at this stage, or the next? Which ones will complete the cycle? The elimination which goes on in the struggle has been called the "survival of the fittest". This expression is quite misleading, for it suggests some absolute quality, a general superiority that is important in itself. But as we have seen (p. 467), the intention of Darwin and of others was to describe something more directly related to a specific situation. Thus the fittest rabbit when rabbits are being chased by dogs or foxes is the swiftest rabbit. But when a severe frost attacks the tribe, the fittest rabbit is the one with the best fur, or the one that has stored up the most fat under the skin during the previous summer and autumn. There is no absolute standard for plants and animals. *Fitness is a relationship between the organism and all the features of its surroundings that may influence it*, including possible enemies, possible food, possible competitors.

We must not read into the story our own likes and dislikes. The wolf and the vulture may be just as *fit* as the sheep and the chicken. The thistle and the ragweed are just as *fit* as the fig-tree and the rose. But no plant species and no animal species can altogether fit in where some other one is now living. The "fitness" of a form, or its adaptation to its surroundings, is of a special kind that it has taken hundreds of thousands of years to attain. When the conditions in any region change radically, the character of the entire vegetation and of the animal life must also change.

What All Species Need All protoplasm depends eventually upon water and air, upon the same few chemical elements, and upon the same classes of chemical compounds. Yet the countless forms of plant and animal life find congenial surroundings in nearly all parts of the world, whereas each species is closely restricted to a rather narrow range of temperature and moisture. We have all been impressed by the striking differences between tropical forms and related arctic forms, or between water animals and related land animals (see illustration, p. 548).

We are accustomed to expect polar bears in Greenland rather than in the Everglades. In Florida we should expect to find alligators. The Canada lynx is distributed throughout a large part of Canada and in some of the northern



THE RELATION OF TRADITIONS AND CUSTOMS TO THE BABY'S CHANCES FOR LIFE

American Museum of Natural History

DIVERGENCE OF RELATED FORMS

Comparing the otter and the skunk, both classed in the "marten family", we cannot see how the supposed ancestor became "modified" into either species. But we are impressed by the fact that species which are so much alike in their fundamental structures do fit such widely different surroundings

parts of the United States, while the koalas and the kangaroos are limited to the continent of Australia. Some species of plants and animals are quite cosmopolitan, ranging over large sections of the earth's surface. Most species, however, are restricted to small areas. Certain giant tortoises and other distinct forms are found only on the Galapagos Islands.

American Museum of Natural History

CONVERGENCE OF DIVERSE FORMS

Marsupials living almost exclusively in Australia and near-by islands resemble in outward appearance various placental mammals living in other parts of the world. How came the koala and the bear to be so much alike? One series of species appears to be as well adapted as the other

A different kind of restriction is illustrated by the fact that clover and alfalfa can grow only where there is an abundance of lime in the soil, whereas blueberries and cranberries, which belong to the heath family, thrive on acid soil. Most seed plants depend upon nitrogen compounds in the soil. Members of the bean family, however, can get along on soils deficient in nitrogen; but

that is because they live in partnership with bacteria that are able to combine, or "fix", nitrogen from the air into compounds that the larger partners can use (see page 152).

Jack Sprat Principle You recall that Jack Sprat could eat no fat, whereas his wife could eat no lean. These two people did not let differences in taste cause ill-feeling and bickering. Instead, according to legend, they managed amicably and sensibly to make the most of their undoubtedly limited resources. They licked the platter clean, and we may assume that both continued to be well nourished. At any rate, we can observe this principle of specialization at work when we consider the wide variety of conditions under which different species of plants and animals thrive. The most obvious specialization is, of course, between water-dwelling species and land-dwelling species. There are many species of plants and animals, however, that live on the margin between land and water—marsh plants and animals, tide-water forms, and so on. Thus ferns, mosses, skunk cabbages, and certain fungi thrive along woodland streams, but are seldom found growing in open fields. Muskrats, cattails, sedges and red-winged blackbirds are associated in marshes or swamps. The amphibians are typical in-between forms, the very life cycle of the frog being adapted to alternation of wetness and dryness. However, living in air and living in water involve such great differences in structure and in behavior that most species live in either one medium or the other.

Adaptation to Change The emergence of many species may be looked upon as an adaptation—in the course of time—to new situations into which living beings are forced by the pressure of population. We have seen that many specialized types of plants and animals do in effect fill in gaps among other species. We may see this more clearly if we consider what happens when a decisive change takes place in climate, for example, or in a river when industrial wastes are discharged into it.

Let us imagine a relatively dry region occupied by plants of many species and a corresponding population of animals. The specialized types fit the physical surroundings—the soil and its chemical contents, the moisture, the temperature, the sunshine. And they fit one another—taller plants and low growths, the insects and the worms, the bacteria and the birds, all make up a fairly constant mixture season after season. But now, if this region should become flooded, a large proportion of both plant and animal inhabitants would be destroyed. Only those that were not too highly specialized would survive, mostly simple plants and animals that can endure a great range of dryness or moisture. Those that are too finicky or else too rigid would be killed off. A marked change in physical conditions always destroys some species.

On the other hand, as the water destroys thousands of individuals of many species, it also favors certain other species—less specialized water-dwellers or forms that thrive in wet situations. Life is destroyed; but life goes on.

Intensification of Life[1] Since all living things carry on essentially the same fundamental processes, animals are, so to say, just like plants—only more so. But that is not quite true, nor all the truth. For plants in general are much more effective food-makers and food-assimilators. A pound of plant protoplasm can become two pounds more quickly than can a pound of animal protoplasm, adequate supplies being assumed, of course, in both cases. And plants can take a great deal more punishment without giving up. But perhaps that is only another way of saying that by means of growth they can more easily make up the injuries they sustain.

This suggests, however, more far-reaching differences. If most animals cannot take so much abuse, they do not have to take it—for they are motile and can get away or hit back. Or they can sense danger at a distance and disappear before trouble reaches them. Most animals are able to carry on—to struggle—in ways that plants generally cannot match.

The rate of metabolism in animals is generally higher. That means that for each unit of protoplasm they use up more food in a given time. But since animals are not food-makers, they spend relatively more time and energy in foraging. These facts suggest differences in the intensity of living, although many animals are fixed in their positions like plants, and others are very sluggish in their movements.

Sensitiveness Animals seem generally much more sensitive than plants, although a passing cloud will change the rate of photosynthesis and of respiration in a plant. If we survey the various types, from the simplest to the more complex, we see more and more specialized sense organs. From the eyespot of the euglena we go to the complex eyes of vertebrates and the cephalopod mollusk—the octopus, for example. From sensitiveness to mechanical disturbance in the ameba and sensitive hairs in the coelenterates (hydra, sea-anemones) we go to the antennae of insects and crustaceans and the ears of vertebrates. From the chemical sense of the paramecium we go to the fine sense of smell in many mammals. Animals seem to extend their contacts with the world, to enlarge the range of the environment to which they relate themselves—and fit themselves. Thus an animal can discover enemies or food at a distance, and act accordingly.

In the case of human beings the sense organs and their connections have made the task of obtaining food and escaping enemies both more complex and easier. The sense organs are "receptors", or receivers of impressions, signals, information, and so on (see page 275). They make the tasks of life easier, for they enable the organism to draw upon greater resources. But they make life more complex too. For they compel the organism to take note of a greater

[1]See No. 5, p. 558.

variety of objects and happenings, some of which might perhaps be just as well ignored.

Discovering the outside world and the practical meanings to us of the various objects—possible utilities, possible dangers—is important in the struggle for existence. But by itself that is not sufficient. Whatever our senses tell us, it is necessary to get action, to produce some effect. Animals have always impressed us with their motility. Not only do they move themselves from place to place, they move other things about. They grasp, they bite, they scratch and claw, they tear apart. Or they fetch and carry, build nests and dams and hives. Some species of ants tend captive plant-lice. Others cultivate fungus plantations. Many animals gather more food than they can eat, and store or hide some of the surplus. They hide themselves away, sometimes for months at a stretch, in natural hollows or in burrows of their own making. Even such going to sleep is a kind of action, for it produces the effect of running away from cold weather and bare pickings, like the more spectacular migrations of birds. All these activities are phases of the urge to live; they are aspects of a *struggle*, which consists of all living activities.

Struggle Patterns We find it difficult to describe the struggle of complex organisms, except in terms of our own activities. We say that the bird (the early one, of course) *catches* the worm, that the fawn *dashes* away from the hounds, that the worm *swallows* earth. We see "struggle" in a pattern of reaching out and grasping for food or other "needs", and of running away, of dodging or escaping, of thrust and parry.

One June, along the inner shore of Cape Cod, a dark spot was seen in the water, a little way off shore, a spot about as large as two or three acres. The dark area was drifting in closer to shore. The darkening of the water was due to millions of tiny mackerel, each some three inches long. These mackerel were milling and churning about as if vainly trying to evade some pursuing enemy. And sure enough, literally thousands of small squid, each about six inches long, were chasing back and forth among the fishes. A squid would dart forward, reverse, grasp two or three of these tiny mackerel in its tentacles, and proceed to devour them.

When we think of "struggle" we usually think also of its outcomes, and especially of whether it is successful. Here was a struggle between the fish and the squid, or between "hunger" and "self-preservation". But was the struggle successful? The squid had plenty of food for some time to come, but they were reducing the number of mackerel. In the absence of squid or of other enemies, the mackerel might conceivably so increase in numbers that most of them would die for want of food. In the absence of mackerel, however, the squid would be devouring other fish, or small crustaceans perhaps. And in any case, most of the squids themselves are sure to be eaten by other animals.

Here, then, is a struggle that never ends—or hardly ever. And it is always

successful—or almost always. That is to say, whichever species succumbs at any moment, it enables others to continue, and so the struggle continues.

A struggle like the one between little fish and larger enemies ends when a still larger animal, like a whale, suddenly swallows several barrelfuls of ocean, with all the hundreds of squirming struggling life. *That* struggle ends—but the vanquished participants enable the whale to continue a while longer. A storm washes out the life of plants and animals in an acre. The struggle of a few moments ago ends. But those destroyed plants and animals now become the raw materials for other living things. Life goes on, now in these forms, now in those others. And so the struggle, which is one way of describing life activities, also continues.

How Does the Human Struggle for Life Differ from That of Other Species?

Man and Other Animals Under certain circumstances, or for certain purposes, man is the same as other animals. But nearly always he is different too. Like animals, we need food to still our hunger. Yet we can learn to postpone eating—for a time—without letting the hunger distress us too much. At the table human beings do not have to claw each other, or even elbow each other, to make sure that each gets enough. We can wait at least long enough to have things passed our way. This fact alone makes a great difference not alone in the manner of eating, but in the whole manner of life. For it means that we can guide conduct by imagining the future, as well as by remembering the past. Man can plan; he can struggle for food between meals, when he is not hungry. Where other animals are driven by the feeling of hunger, man acts to avoid hunger. He can shape his conduct through ideas or knowledge.

Fighting Drives We can make almost any animal fighting mad by striking it, or by stopping it as it is chasing possible prey, or by taking its food away from it. In general, man fights under very much the same circumstances as other animals. When there is not enough food (or other things they want), men will fight other animals, and they will fight one another. When men are blocked in their efforts, they will fight those who obstruct them.

Animals can be aroused to fight by a threat or a gesture—as if you were about to strike. But man alone can be aroused to fighting by words in a newspaper or on a banner. When the jocular shepherd boy shouts "Wolf! Wolf!" in a certain tone of voice, other shepherds come rushing along *as if* there were really wolves to fight. Or when another humorist shouts "Fire! Fire!" he can drive perfectly sensible people into a panic. We can be deceived into fighting imaginary enemies, and by imaginary fears. We can also be deceived into submitting to abuses, into remaining quiet while we are being robbed.

We can imagine so much more than we can experience that we sometimes

become the victims of our very excellence. For we can imagine what has nothing to do with the facts of the world—that is, we can be mistaken, we can deceive ourselves. Human beings use cleverness and deceit not only in fighting their natural enemies, but also in fighting each other. In fact, many consider the conflict of man with man as the best means of advancing mankind, as well as the most satisfactory expression of individual human life.

Man as Social Organism Man has overcome his organic handicaps largely through his disposition to form groups, to co-operate, or act jointly, with others. Community action may be observed at every level of life, and is in fact the central advantage in all higher organisms. Men live in communities and identify themselves with their families and their neighborhoods and their towns and tribes and nations. They can therefore be aroused to fight and to sacrifice for "their own", for the interests of the larger group, which is truly their own deeper or larger self.

Through his inventiveness and imagination man can change the methods of his fighting, as he can completely change the goals of his struggles. When man discovers that he can get all he wants of those things that animals fight for, he turns his efforts to fight for what he considers greater values, or more worthy objectives. Men will fight for honor or for the glory of some group or institution. They will fight for ideas, for liberty, for security, for their heroes and leaders.

Struggle and Competition By the middle of the last century the old patterns of agricultural life and production through handicrafts were beginning to change rapidly. Industrial developments and the means of transportation and communication had already reached a very high stage. Machinery was coming to be more economical than slave labor.

Where families had been living largely through their own labors on their own land, some families thrived better than others because of differences in skill and intelligence. Now the organization of industry and commerce was intensifying the competition among individuals, among groups of individuals, among different regions, and even among different nations. Migrations from country to country and from farms to cities brought together peoples with many different kinds of backgrounds and abilities. And a large proportion of the transplanted organisms did not "fit" their new surroundings and conditions.

When we look back over what has happened in about a century and a half, it seems natural that people should have been influenced by these rapid and extensive transformations in their ways of living. The atmosphere was full of "struggle" and "competition" and "success". This was, of course, very distressing to those who had been brought up in more peaceful surroundings and friendly relationships. It was becoming necessary to justify competition as "right", since it not only brought great suffering to many, but was actively opposed as unsound socially and morally.

When fierce competition was the prevailing pattern in human affairs, it is not so strange that several scientists simultaneously came to the same interpretation of what happens to plant and animal species through the ages. As we have seen, Charles Darwin and Alfred Russel Wallace independently hit upon the idea of "survival of the fittest in the struggle for existence" as an explanation of how new species arose (see page 466).

We may well believe that neither Darwin nor Wallace had the slightest intention of connecting his scientific ideas with business or politics. For years at a stretch Wallace was away in the tropics exploring, far from public discussions. And although Darwin lived in England most of the time after his early voyages, his life too was far removed from political and economic questions. It is therefore interesting to see not only that their thoughts converged in this way, but also that many immediately seized these ideas to get the support of science for their way of carrying on affairs.

The doctrine that "nature selects" the "fittest" by forcing all living beings to "struggle for existence" against great odds appeared to justify intensive competition as a means of ensuring "justice" and "progress". Competition results in justice because it enables the "fittest" to get ahead of the others. It makes for "progress" because it forces the less able out.

Men Must Fight As we have seen, dividing tasks up more and more makes it possible—and necessary—for more and more individuals to attend to problems that are *not* life-and-death issues (see page 530). Human life could go on if nobody ever crossed the ocean or made stainless steel or ever broke another speed record. At the same time fewer men have to struggle with wolves or bears or fight snakes and tigers.

The struggle has taken on new forms and calls for new skills. But it also calls for primitive qualities of courage, of hitting hard, of fortitude and endurance, of shrewdness and wile. We are not much concerned with old fighting skills and tricks, but we still value the qualities of warriors and heroes; we still go out for risk and adventure. We are concerned with carrying out more quickly and more efficiently a great variety of acts that are utterly meaningless in themselves, but that are related to the lives of vast multitudes. Thus men spend hours boring holes in the earth or in various kinds of stuff, in loading parcels into cars, in transferring fluid from one tank to another, in piling up stones, in sharpening tools, in polishing doorknobs, or in mixing mortar or dyes or insect sprays.

These various specialized tasks are not interesting in themselves and are likely to become rather dull. They are not always obviously related to human welfare. Nevertheless we come to realize how completely each of us depends upon what all the others are doing—or fail to do. We come to appreciate the necessity for teamwork, for fitting our own activities into a common program of action.

In more recent times, communication has been rapidly extended and speeded up. Processes based upon scientific research have become extremely specialized and refined. We have become aware of our dependence upon a larger and larger group. In an epidemic, for example, the individual who relies only on himself is completely helpless in spite of his intelligence or good intentions or bank account or special talents or other powers and fighting qualities. His salvation depends upon various specialists in all parts of the world, working night and day to protect—not him personally, nor themselves, but the entire community or region. When there is a flood or a plane crash or a hurricane, the damage done is usually unrelated to the virtues or the physical strength of the men and women and children who get thrown around. But from such disasters we often learn how future damage may be avoided or reduced. And dealing with the immediate disaster and guarding against future repetitions create fighting jobs. But these jobs are only for people who can see danger or the "enemy" in natural processes, and who can see the goal of striving in broad human needs. Fighting spirit and fighting qualities are constantly needed. But the struggle need not always be on the level of a hungry fox or of two dogs tearing at the same scrap of meat.

The Moral Equivalent of War Men will fight. But will they fight like pigs over the contents of the feeding trough, spoiling more than they use? or like other beasts, over the scraps in the garbage cans? Will they fight like bandits or marauders, preying upon strangers? or like gangsters, holding up anybody who may come along? or like racketeers dressed up like civilized people, pretending to render a service—quacks looking like doctors, shysters disguised as counselors, embezzlers offering to help widows and orphans with their financial problems? Will they fight in organized armies, trying to ensure their own survival at the expense of inhabitants of other regions? Or, eventually, will men fight as human beings, using their talents and skills and ingenuities and sciences to overcome the many obstacles to decent living? Will they attack the common need for abundant supplies of the earth's yield? Will they fight to overcome pests and pestilences, to prevent and cure human ills, to clear jungles and swamps, to restore the soil, to build highways, span rivers, tunnel mountains?

Human beings are engaged in the same struggle for existence as are mice and mildews and mosquitoes. They have a larger world to conquer, and more delicate, as well as more powerful, weapons to fight with. The goals they set themselves depend upon the ideas they have of their own natures and needs, and upon their notions about the world they seek to conquer. The courage and energy and spirit with which they conduct their fight depend upon their appreciation of dangers and needs. Men content to fight for bread alone will hardly get more out of life. If men imagine a world of general health and general well-being, they may never be able quite to realize their dreams. But

they will, at any rate, use different methods. These methods of mutual aid and of striving for common ends are also ways of fighting. They involve what William James (1842–1910), the great American psychologist, called "the moral equivalent of war".

In Brief

The processes in a living plant or animal include *attacks* upon the outer world and *resistance* to attacks from that outer world, which together make up the "struggle for existence".

To live at all an individual plant or animal must be adapted, or fit, to get the essentials and to avoid destruction in the specific conditions of its environs.

The competitive aspects of plant and animal life come from the pressure of population upon the means of subsistence.

Most individual plants and animals are probably eliminated by chance rather than by specific failures or deficiencies.

"Self-preservation" is the persistence of an organism's working unity under changing conditions and under attacks from outside.

Man, like other species of animals, is a fighter, being aggressive in the pursuit of his goals and aroused when balked.

Man's modes of fighting are influenced not alone by the opposition he meets, but by the multitudes of special weapons and skills accumulated in his culture and by his being a member of a co-ordinated social group.

The goals which human beings set themselves are influenced by their understandings of their own nature and needs and of the nature of the world, and by their feelings as to what is of value—whether food or shelter or home and security or honor and liberty.

Men have joined together to use their skills and talents and imagination to build for the future, to avoid hunger, to increase security, and to overcome obstacles to decent living.

Perhaps men will eventually use all their resources jointly for attaining common benefits, rather than for getting special group advantages at the expense of others.

EXPLORATIONS AND PROJECTS

1 To investigate the "struggles" of plants, make a survey of the number of different species present within a limited area. Select a wild spot twenty-five feet in diameter having as wide a variety of conditions and vegetation as possible. Using general and common names rather than exact scientific ones, list all the organisms found living within the area. Which kinds of plants are dominant? Which of their

distinctive qualities fit them to grow in the region where you find them? In what respects are the dominant forms competing with other species? with individuals of the same species? What animal forms gain their living directly or indirectly from the vegetation studied? Summarize your findings.

2 To study the characteristics which qualify a plant as a "weed", collect several weeds from cultivated fields and find out in what ways they seem particularly adapted to grow and reproduce. What is there about the roots, stems, leaves, fruits or seeds that particularly fit these plants to compete successfully with crop plants?

3 To see whether weed seeds or seeds of cultivated plants sprout faster, mix several varieties of weed seeds with garden-flower seeds and grow in a box under optimal conditions. Chart the individual germination and early growth of the various seeds and plants day by day to show variations in *rates.* Summarize and interpret your findings.

4 To find out how plants escape being eaten, study as many different plants as you can to see what special characteristics about them are likely to repel animals. List the plants and describe or picture the protective adaptations of each.

5 To study the various adaptive structures, list a number of animals under observation, and opposite each name state the structures and other characteristics that enable the animal (*a*) to get food and (*b*) to escape enemies. Summarize your findings.

QUESTIONS

1 What various activities are carried on by animals in their "struggle for existence"?

2 In what sense do plants "struggle"?

3 In what ways does the "struggle for existence" among animals resemble that among plants? In what ways do the two differ?

4 What is the connection between fitness and environment?

5 To what extent are the factors which determine whether or not an organism will live and reproduce *selective*? To what extent mere chance?

6 How do radical changes in the physical conditions of a region bring about changes in the vegetation and animal life?

7 What are the advantages that come to man from his social mode of life? What are the disadvantages?

8 What other species show a high degree of social organization? In what respects is the social life of these organisms like man's? In what ways is it different?

9 How does the struggle for existence among men resemble that among other animals? In what ways does it differ?

10 Upon what assumptions do men base their goals, or aims? To what extent can better understandings improve or redirect the goals of men?

11 How can we direct the "struggles" of men away from getting special advantages at the expense of others to striving to attain the greatest benefits for all?

1. Why cannot any species of plant or animal live entirely alone?
2. Can the individuals of a species live by themselves?
3. Are parasites of any use?
4. Are weeds of any use?
5. Can a plant or animal be useful to some species and injurious to others?
6. Does the number of individuals in a species remain about the same year after year?
7. Could we make all land surfaces bear only useful plants?
8. Is the division of labor among different species the same as the division of labor among the members of a beehive?
9. Could we get rid of all injurious plants and animals?

Many a poet has sung about an island on which he might be alone, or sighed for the wings of a dove on which to fly to the solitude of some vast wilderness. And many a hermit has actually gone off, expecting to find comfort and peace, as well as abundance and elbowroom, far from other men.

It is easy to understand why one should want to escape from hardships and annoyances that he cannot overcome or thrust out of his life. But if one had the whole world to himself, he would not get very far. Each of the multitude of species can continue generation after generation only because many of the other species also continue to live. Through the ages life has come to be a complex of many species acting upon each other in ways that are often mutually destructive, but such a complex seems to make possible the greatest total amount of living matter—in a particular region or in general.

Cannot any species live entirely alone? What happens to the others if any species dies out? What happens to repopulate a region in which all life has been destroyed?

Could Any Organism Live by Itself?

Life and Light All organic matter seems to derive from carbohydrates, which, so far as we know, arise only from the action of light on chlorophyl. We should therefore expect the first forms of life in any region or in the world to have been green plants. Certainly no animal of the kinds living today, and no plant lacking chlorophyl, could live before other plants or animals had left some of their substance that might be used as food.

We do not know that the earliest forms of life were "green plants". It is conceivable that such compounds as viruses and enzymes developed into some kinds of "living" forms before chlorophyl-bearing species appeared (see page

444). If there were only green plants in the world, all the carbon dioxide would at last be used up. Any plant that died would permanently retain its carbon compounds and so keep carbon out of circulation, since under such conditions nothing would decay.

The Food Cycle[1] Under the sod, where it is too dark for green plants to make new carbohydrates, we find hundreds of species of bacteria, fungi, larvae of various insects, snails, moles, ant colonies, many kinds of "worms" and perhaps snakes. Some of these organisms live on the roots of plants that hold their crowns or leaves above the ground. The larger or the more active of the animals move out of their burrows and gather food above the ground. The ants, for example, forage on leaves, on various bits of dead organic matter, and on plant lice. Sometimes a swarm of ants will attack a living caterpillar or other insect that is not too active.

Earthworms live on dead leaves and other plant parts, and on dead organic particles in the soil. A worm swallows masses of earth and digests the organic contents in the food tract. Snakes come out for their prey, as do ants. Through the processes of decay, bacteria and fungi release the proteins, fats and carbohydrates locked up in dead plants and animals. As a result, these organic compounds break down into carbon dioxide, water, urea, ammonia salts, and other nitrogenous compounds.

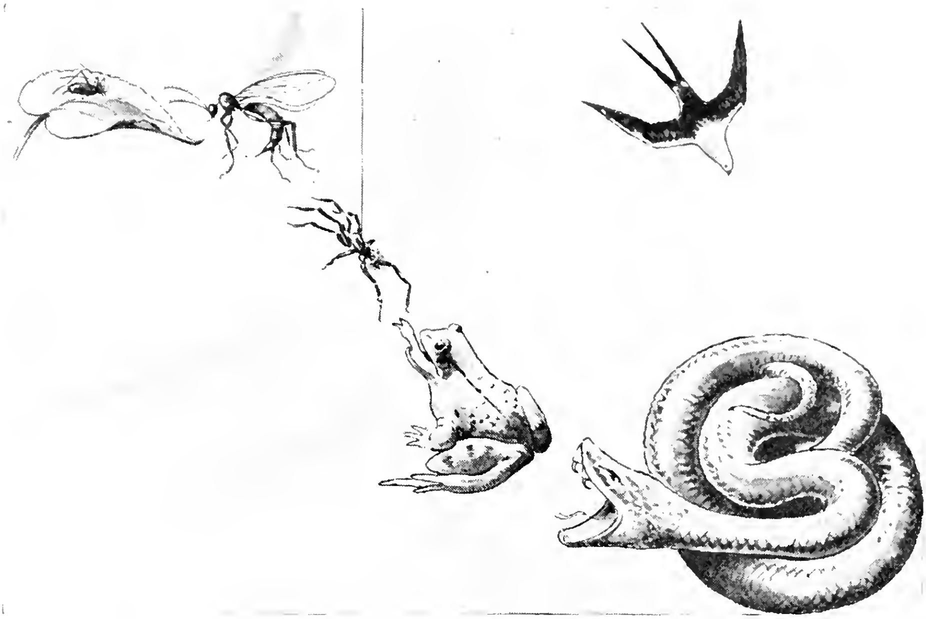
Many of the inhabitants of the soil are parasitic on others. And all plants and animals discharge into the soil some of the products of metabolism, or wastes. As a result, carbon, nitrogen, sulfur, and other materials return to the air and water and soil, and become again and again incorporated in living bodies, taking part for longer or shorter periods in "being alive" (see illustrations, pp. 150, 151).

Each organism that is not a food-maker gets food from others, and in turn supplies food to others. Plants and animals thus stand in a sort of continuous food "chain". This is not exactly a friendly give-and-take, since it seems to run in one direction only. Beginning with the simplest chlorophyl-bearing plants, the species in a food chain become generally larger and larger.

There is, however, a limit to this chain. This does not mean that the largest trees or the largest animals are free of all enemies. It means merely that there are other ways of getting food besides that of destroying smaller neighbors. As practically everybody knows, small fleas "have smaller still to bite 'em; And so proceed *ad infinitum*." Parasites are also links in the food chain. In this series the plants and animals become smaller and smaller, although, as with the main food chain, there are exceptions at many points. It does not follow, for example, that flesh-eating "cats" are larger than those vegetarian deer upon which they prey. A lion can successfully attack a giraffe.

Flesh-eating animals that travel in packs or work in gangs often have ad-

[1]See Nos. 1, 2, and 3, p. 576.



Lawrence B. Robbins

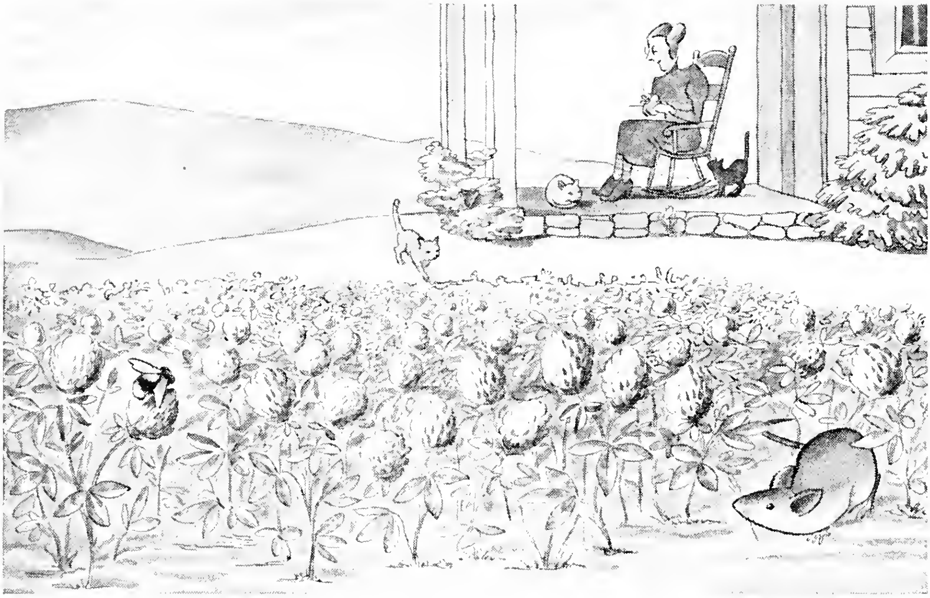
A FOOD CHAIN

Beginning with the simplest chlorophyl-bearing plants, each organism eats, and in turn is eaten. Animals generally get their food from those that are smaller. Each takes what he can and gives only what he must

vantages over larger animals. Wolves will attack a herd of cattle or deer. The driver ants, which always travel in vast regiments, will attack large animals—lizards, snakes, and even cattle. If the latter cannot escape the swarm by running away, the countless ants will sting it to death and carry off the flesh bit by bit. Not all flesh-eaters, however, are compact and energetic fighters. The whale, for example, takes into its mouth a fraction of the ocean, filters out most of the water, and finally swallows some hundred pounds of small fry.

As we should expect, a species that serves as food must be more numerous than another which feeds upon it. It is estimated, for example, that one lion may kill as many as forty or fifty zebras in the course of a year. Since many zebras must die every year without waiting for lions to kill them, the ratio of zebras to lions must be much greater if zebras are to survive—or, for that matter, if the lions are to survive. For if lions destroy too much of their food supply, it will go hard with them the following season. To be sure, lions can feed on other animals besides zebras; but the principle is still the same.

The food chain is in a sense endless. Or rather, it goes round and round, as we saw in considering food cycles. A single shrub may have on it millions of plant lice. These plant lice furnish food for thousands of insects and spiders.



CLOVER CROP DEPENDS ON SPINSTERS

The red clover prospers if there are plenty of bumblebees (which are able, however, to thrive on other plants). But bumblebees are destroyed by field mice, which are kept in check by cats. If certain kind ladies did not harbor the cats, the mice might become too numerous and destroy the bumblebees, and we should then not be in clover

These in turn are devoured by a dozen or a score of small birds. But these birds can barely supply a single pair of hawks or a domestic cat. The hawks or cats do not, of course, finish the cycle, even if they have no serious enemies to contend with. For if there are no enemies large enough to destroy them, the parasitic chain gets in its work sooner or later. Exceptional prosperity leads to high density of population—which invites an epidemic. An epidemic in turn exhausts itself, or it is destroyed by another epidemic.

Natural Groupings of Organisms We can separate a plant or an animal from others of the same or of other species. But we cannot keep it alive in isolation indefinitely. The organism depends upon other species in its natural setting—on some directly as food, on others indirectly as food for its prey or host. The cat seems not to care much about clover; but she can feed on field mice only because the clover and the bumblebee have an arrangement of their own.

When you see a field aglow with fireweed or black-eyed Susan, you may be sure it was the winds of pure chance that brought the seeds. Yet the insects which now fly around those flowers were directed by something more definite. And whatever becomes of the next crop of seeds, these insects will

have had a share in bringing them into existence. We notice in any region chiefly the plants, both because they stay put and because they are usually present in masses of individuals of the same kind. The animals manage for the most part to remain out of sight. The many species of plants and animals of any region, however, make up a coherent whole.

The different species depend upon one another not alone in the food chains —or, rather, food cycles. They depend upon each other also for "shelter". Thus birds and mammals hide in the trees, or smaller plants live in the shade of larger ones. And they depend upon each other for "services"—as in the case of insects transporting pollen or of mammals transporting seeds. We may regard some of the activities as in the nature of "protection"—as when ants keep the plant lice in check on a shrub. Such a grouping of many different species that depend upon each other in these different ways is sometimes called a "natural community".

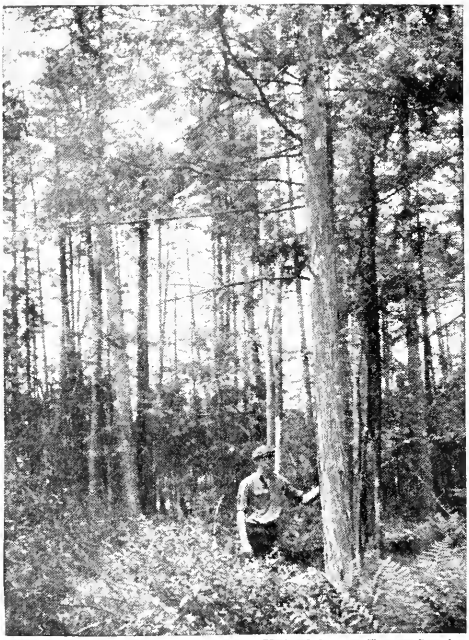
What Determines the Composition of Natural Communities?

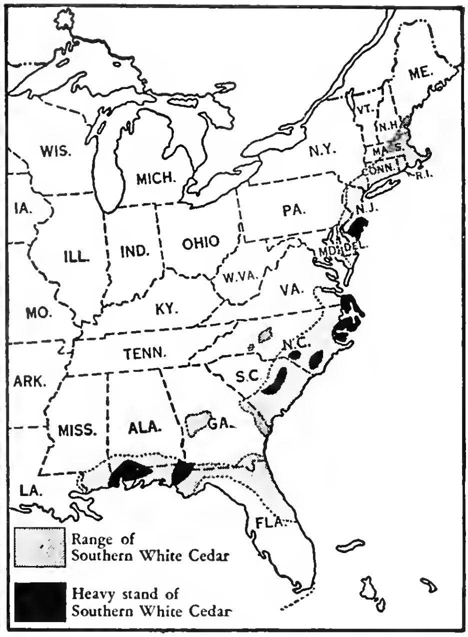
Life on the March In every plant and animal species population constantly presses in all directions. From wherever there is an established population, to wherever it can find a place to take hold, life is on the move. What enables species to move forward? What obstructs this movement?

The climate, the contours of the earth, large bodies of water, may restrict some plants and animals pretty closely. On the other hand, winds carry seeds and spores over all kinds of obstacles, and the rivers distribute living forms. Ocean forms become widely distributed, being restricted chiefly by climatic conditions. The birds often fly over obstacles that block other species, and they often carry seeds and spores far from their place of origin.

On the relatively low mountains in the eastern United States, for example, one finds species of plants and animals that are typical of the Canadian zone of life. Plants on the barren tops of these mountains are typical of the arctic region and of the higher Alps, the so-called Arctic Alpine life zone. It is quite a thrill to recognize one of these Alpine species after an exhilarating climb to the summit. Lichens and mosses grow on barren rocks and in protected crevices above the timber line, under climatic conditions which no higher forms of life can long endure.

There is much evidence to show that the distribution of plants and animals today is in some ways unlike that of the distant past. Thus we find in the arctic coal deposits which must have been produced ages ago, although the conditions there today are impossible for plants that can form coal. How did coal deposits get into the arctic regions? Was the coal formed farther south and then somehow shifted into the arctic? Or were conditions in these parts of the world favorable to plant life in past ages?





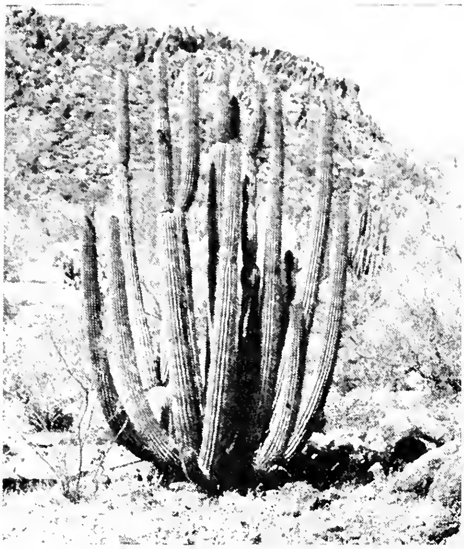
United States Forest Service

RELATED INDIVIDUALS IN SCATTERED REGIONS

This "southern white cedar" (Chamaecyparis thyoides), growing in Connecticut, is really a kind of cypress and grows on the margins of swamps. But swamps are infrequent to the north of central New Jersey, while the plant is found on their margins as far as Maine. How can we account for the distribution of this species in such widely separated areas?

The prickly-pear cactus, which is common only in desert regions, is found also in a few isolated barren localities in the highlands of New York and northern New Jersey. How is it that we find these plants so far removed from their normal range? One suggested explanation assumes that after the retreat of the last glacier, warm, arid conditions prevailed throughout most of the northeastern United States, so that plants requiring more moisture died out; only desert plants survived, and they spread all the way from New Mexico to New York. With changing conditions other plants have replaced the cacti over most of the area. Another situation which is similarly explained is the presence of the southern white cedar on the margins of fresh-water swamps in lower New York State; this is a species that normally ranges southward from the Carolinas.

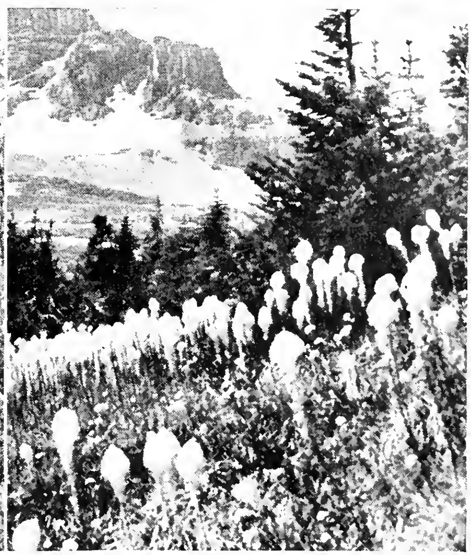
Barriers to Migration Species living on a highland, or on a continent widely separated from other continents by oceans, have little chance to visit other lands. The living forms or types found in such isolated places are often unique. For example, British explorers found no placental mammals in Australia in the decades after it was discovered by Captain Cook. This was not a



Organ-pipe cactus in a desert habitat — southern Arizona

Dune grass on a wind-swept seashore — Cape Hatteras

Epiphytes in cypress trees in a swamp habitat— Everglades, Florida



United States Department of the Interior; Glacier National Park

Bear grass at the summit of the Rockies — Glacier National Park

TYPES OF NATURAL COMMUNITIES

If placed in one of the other environments shown, any of these distinctive plants would be crowded out by the native species, or it would be destroyed by the inorganic conditions

question of "fitness", for when rabbits were later introduced, they multiplied rapidly among the native marsupials, and actually became a pest.

The most effective barriers or obstacles to migration may turn out to be a relatively small feature of the soil or the population. Acres of seemingly good earth may remain sterile for want of a chemical element which plants use in very small quantities at most, such as magnesium. On the other hand, early settlers may obstruct migration, either by pre-empting all the available space or by being actively antagonistic. Human wanderers have frequently been stopped by micro-organisms producing tropical diseases rather than by wild beasts or by previous settlers.

Types of Community To most of us a forest is the most familiar natural community. The inhabitants of a desert make up quite as distinct a community, but most of us would have to be shown, since we commonly think of a desert as having no life at all. A swamp has its characteristic plants and animals, as has a scrub or a sand-dune.

The inhabitants of the ocean differ from those of fresh-water lakes, but there are many types of communities in the former and also in the latter. Tidewater plants and animals differ in many ways from those that occupy the bottom offshore, as well as from those that live at or near the surface. And deep-sea forms differ from both (see illustration opposite). Brook life and pond life differ from each other, and they differ also from the forms living in larger streams and in large lakes. Among the most important life communities in this country are the grasslands—of two types, the semiarid plains and the moister prairies—which have played a great role in the development of our food resources (see illustrations, pp. 89, 569, 643, 646).

How Are Communities Formed?

The First Settlers To a barren spot containing no organisms whatever, the winds would ordinarily bring thousands of seeds and spores representing dozens of species. Which species could take hold would depend upon the amount of moisture, the temperature, the sunlight, and the chemical condition of the soil. To establish themselves in such a barren situation, plants must be able to endure the winds, glaring sunlight, extreme fluctuations in temperature and in moisture, and extreme combinations of soil chemicals. Most of the plants with which we are familiar could not endure so much pulling and pushing. Early settlers have to be tough.

The pleuroccus cell might hold on to the rough surface of a rock. If there is enough moisture in the air, it may grow and multiply. But then, it cannot stand sunlight. The gemmule of a lichen might do better, since the fungus partner can absorb enough moisture from the atmosphere to supply both itself and the algal partner (see Appendix A). The excretions of the lichen gradually dissolve some of the rock's surface and so contribute to the making of soil.

Else Bostelmann

OCEAN DEPTH AND OCEAN SURFACE

Ocean animals living near the surface depend for food upon green plants and a chain of larger and larger animals. In the depths, where chlorophyl action is impossible, larger animals feed upon smaller ones, down to worms and protozoa, all finally depending upon the decomposition going on at the bottom

To establish themselves in a barren region tough seed-plants must be able to push their roots down rather quickly. They usually have harsh skin, often prickly surfaces or hairy coatings, and can endure extreme changes in moisture and in temperature. Such "pioneers" are able to make a living in rather unpromising conditions. Through this very growth, however, these pioneers change the surroundings. The roots break up the soil and make the latter fit for more tender plants. The dead leaves falling to the ground make a blanket that retains moisture: now the earth does not dry so quickly after a rain. Organic matter slowly accumulates and gets into the soil. In the shade of pioneers the seeds of more tender plants can get started. In time these early settlers change the soil, and the climate close to the ground. They have made an environment suitable for other species of plants. They have provided also a setting for insects, worms, and bacteria and other nongreen species.

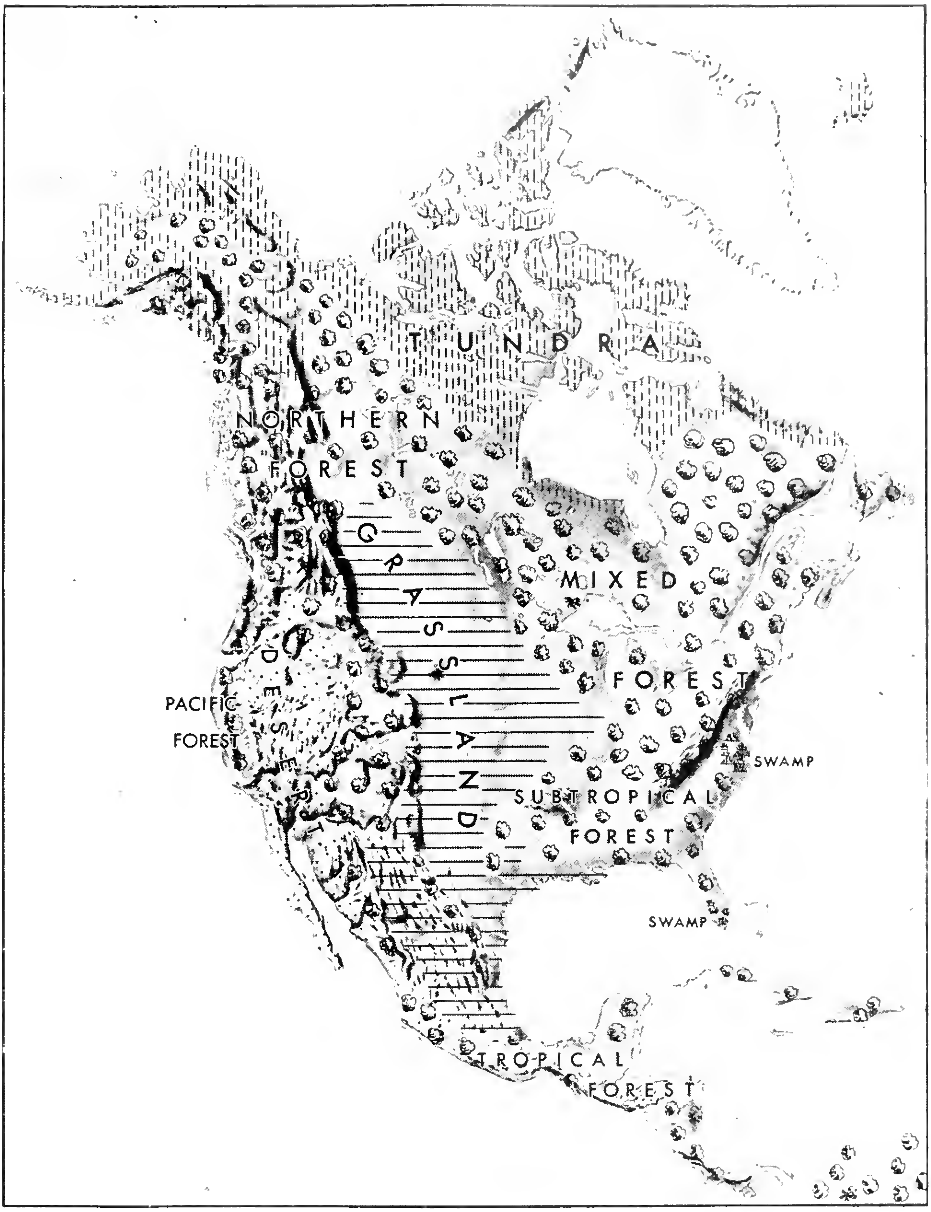
The first animals to arrive in such a situation may find little to attract them or to hold them. In time, however, food becomes available for more kinds of plant-eating species. The remains of dead plants and animals supply conditions suitable for scavenger animals like certain kinds of worms and insects, and for decay organisms—bacteria, yeasts, fungi. Roaming birds and other animals act as carriers—whether they remain or pass on. They bring new kinds of seeds, as well as worms, protozoa, and insect species small enough to take the ride, whether inside or outside the bodies of the larger forms.

Changing Population The pioneer seed-plants are not merely tough in relation to the physical and chemical conditions. They must also be self-sufficient for pollenation. Or they must at least be able to get along with wind and gravity, and not depend upon insects or birds. After insects arrive, there may be a chance for the more sophisticated species of plants that do depend upon insects. In much the same way, seeds of legumes (plants of the bean family) may get started; but unless the right kinds of soil-bacteria are also present, they will not be able to establish themselves (see pages 149, 151).

The composition of a living population is thus constantly changing. Some species become relatively more numerous. There are constantly new arrivals. Some of the new settlers expand rapidly. Some of the early settlers gradually disappear: they are crowded out, or they die out. In some cases, plants and animals take on new patterns of living. A plant whose ancestors lived on moist soil has now leaf habits and root habits that enable it to live in the drier region. Or an insect whose ancestors lived for generations on a particular species of plant takes to a different diet. But most species apparently make no experiments unless driven by "hunger".

The Climax Community[1] Plants of different species are constantly competing for the limited amounts of water and of minerals in the soil. Some compete for sunshine, although others thrive in the shade of their taller

[1]See No. 4, p. 576.



LAND TYPES OF NORTH AMERICA

The characteristic plants of a region are determined, in a sense, by the nature of the soil, the water supply, the climate. The animals in turn are determined by the characteristic plants. But in time the plants depend upon the animal population as much as the animals depend upon the plants

neighbors. Changes through the seasons and the years affect not only the composition of the population, but also the composition of the soils. And there is also some effect upon the climate. For example, the conditions of moisture, light, temperature, and air movement close to the ground in a forest are quite different from the corresponding features on a prairie; and they are made different as the plant-and-animal community develops.

Of two species living side by side, one may *grow* faster and shoot up into the air. But the other may *mature* more quickly and shoot a thousand seeds into the air before the first one has started to flower. The quick grower may fill an acre in the second year; the other, however, may spread over six acres. These differences are, of course, not the only ones. Nor do they tell us which species will in the end survive.

Through the interactions of plants and animals, of organisms and the soil and the immediate atmosphere, the composition of a population gradually reaches an optimum for the region. There is a balance between the chlorophyl organisms and the others. There is a balance between plant-eaters and flesh-eaters, between insects and birds feeding on insects, between plants that supply nectar to insects and insects that pollenate the flowers, between the number of nuts and the number of squirrels.

When this state is reached, it may continue indefinitely. It is called a *climax* of life development, since it represents the fullest continuous yield of life for the region. And because particular types of plants are characteristic in such situations, various formations are usually designated by the names of "dominant" plant species—for example, a pine forest, a tamarack swamp, a scrub-oak mountaintop, a maple-birch community, and so on (see illustrations, pp. 204 and 564).

Moving Equilibrium In a stabilized, or climax, formation all the various species are mutually adjusted in equilibrium. And the whole living population is in equilibrium with the physical conditions. Soil, climate, plants and animals make up together a complete whole. All the parts are related to each other in such a way that the "whole" remains pretty much the same, although changes are going on in every part all the time.

When the climax has been reached, each species reproduces itself at a rate that keeps its numbers about the same year after year. Many species that were conspicuous early in the development have disappeared, and new ones seldom make their appearance. Moreover, the kinds of organisms that thrived at one stage of the development cannot thrive in a later stage. Weeds are usually tougher plants than our cultivated varieties, and they are always pushing out into unoccupied spaces. But they are generally not so efficient where the soil and the other inhabitants have become adapted to a more advanced stage.

Because the larger plants are always the most conspicuous features of such

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DIVERSE APPEARANCE IN RELATED SPECIES

Anybody can recognize all these animals as chipmunks. It is not so easy to tell how their differences came about. Are they the "same species", developing different sizes or colorations on account of the conditions under which they live? Are the differences in any sense of "value" — the dark ones being better protected, for example, in one region and the light ones in another? Are some larger because food is more abundant — or smaller because some particular detail in their surroundings prevents full development? Are they, indeed, the "same species"?

stable life communities, we often overlook the close interdependence among all the species. We are especially likely to overlook the smaller plants and animals in the soil or in dark corners—just as we often overlook the obscure parts of a human population when we travel about, and judge a community or a civilization by some conspicuous features.

It is of course reasonable for us to cut trees for our use or to capture animals for their furs or to catch fish for food. Like other things, we have to get from nature what we need. And timber, food, fur, are the values that we see in these various life communities. It should be clear, however, that in a stable life community, in nature as well as in a human civilization, no individual and no species can live by itself—nor, very long, for itself. Each can live only as a member of the larger group, and this group continues only as its essential members maintain a due balance of numbers and of activities.

Is Man a Member of a Natural Community?

Man an Interloper Man is apparently a late arrival among the many species of living things, in a world already old. We can hardly suppose that he had a place all ready and waiting for him. Like other species, he must have had quite a struggle to make a place for himself. But where?

Today man is more widely spread over the face of the earth than any other species, except the simplest water-dwelling animals. We must except also the parasites that man has taken with him, and some of the domesticated animals, especially the dog. Man today finds himself at home in the tropical jungle and amid the arctic snows, in fertile river valleys and on relatively dry plateaus, along the seashore and in the mountains, in forests and on the open plains.

Always, however, man could migrate only into regions that had already established an equilibrium of plants and animals. For only there was there a sufficient variety and sufficient number of living beings to supply him sufficient food and sufficient materials for shelter against the weather and against dangerous animals.

Man the Wanderer The spread of the human species to nearly all corners of the earth took many thousands of years. It is only in recent centuries that the human population seems to have increased rapidly. And only in modern times has it been possible to observe closely the processes by which man extends his sway over the earth. The earliest settlers from Europe in North America found small encampments of Indians occupying but sparsely a vast forest on very good land. As these new arrivals from Europe all came from crowded regions, everybody eagerly reached out for as many acres as possible. Very often they seized many more acres than they could ever use. One result was that after the first colonies had become fairly well established

Although man uses more different species of plants and animals than any other living form, he manages to make himself at home where few other species can remain alive, and to make himself a home out of almost any material that comes to hand — the snow in Greenland, skins and sticks in Saskatchewan, the sun-dried clay in Arizona

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along the Atlantic coast, the pioneers moved on into the wilderness and spread out. Each farm or settlement then became pretty much a self-sustaining unit, usually some miles from the nearest neighbors.

These human pioneers had to do everything themselves, under difficult conditions. Men, women and children, like plant pioneers in the wilderness, had to be "tough". They had to fight not only the soil and the weather and wild animals, but also the Indians whom they were displacing and other migrant pioneers, other colonials.

From old settlements and farms waves of pioneers kept pushing out, generally westward. Basically, the onward drive comes from the simple fact that agricultural populations always outgrow their lands. But today, as increasingly for a hundred years, surplus farm population is not seeking new lands so much as new opportunities in towns and cities. Farmers have been coming to town in ever greater numbers. The farms have been supplying not only their plant and animal products to feed city dwellers, but also the boys and girls to become city dwellers to swell the urban population.

Human Communities We have seen that plant "pioneers" are tough. In the formation of a natural community the composition of the population changes through the arrival of new *species*. These can live in the new surroundings which their predecessors created. And, on the whole, they can put the material resources and conditions to better use than their predecessors did.

In the wilderness, men, women and children, like plant pioneers, have to be tough. They have to fight the soil and the wild animals and the weather —and sometimes other human beings. As human communities develop, the population consists continuously of members of the same species. New modes of life are developed, differing from those suited to pioneer conditions. The community offers new opportunities, but it also makes new demands. Division of labor and specialization increase efficiency, but they increase mutual dependence and demand more co-operation and mutual consideration.

As in the natural community, a growing human community makes it possible for more tender types to flourish. The skilled craftsman need not be able to do all the different things a pioneer has to do. He is of value in the larger group because he does his own job so well—and there are enough people to use all he can produce. On the other hand, as the number and variety of these tender specialists increase, it becomes "tougher" for the tough pioneer type. He is relatively inefficient in every job he is capable of doing. Skilled miners and skilled farmers become "unskilled laborers" when they look for city jobs. Even if such a pioneer is still tough, the tender engineers and mechanics soon find ways of doing without his heavy muscle, just as they have learned to do without his mule or ox.

There are other hardships for the pioneer. He was able to meet pioneer difficulties through his self-reliance, his physical strength and endurance, his

resistance—his toughness. In the city, however, he has to observe a hundred restrictions and interferences. There are traffic regulations; he cannot come and go as he pleases. He has to step aside or adjust his pace to that of others. He cannot spit whenever or wherever he feels like spitting. He is constantly reminded that he may be making a nuisance of himself. There are demands upon his manners, his dress, his speech. These all "cramp his style". And yet he cannot get tough with these tender people. They have even specialized here: toughness is handled by the police.

Social Integration The human community, like the natural community, becomes progressively more integrated, or unified. The increasing variety of activities become more and more closely co-ordinated. And they become more and more closely related to the *outside.* The rural and the urban, for example, become more closely knit. Manufacturing, or processing, becomes more closely related to production of raw materials and to the machinery of marketing or distributing. Transportation and communication services multiply out of all proportion to the growth of population.

All these changes mean closer interdependence. Each individual must be more sensitive to the moods and needs of others, must be more tolerant of others, more ready to give, as well as to take. And interdependence extends to an ever larger area as interchange of goods and services covers eventually the whole earth; and civilized man becomes at last a citizen of the world community. The ruggedness of the individual who minds his own business and disregards everybody seems to be out of place.

Man and Other Communities[1] When an equilibrium is reached, whether in a natural community or in a human community, it may be disturbed by a variety of happenings. By a radical change in climate, for example, as has happened repeatedly in the past, or by a volcanic eruption, an earthquake, a flood, the diversion of a river, a hurricane. But again and again a natural community of plants and animals has been seriously disturbed by the intrusion of one restless, roving, ruthless species—man. Man makes his own community and tries to subordinate the rest of life to his purposes. And sometimes he destroys the very beings upon which his further existence depends.

In Brief

Decay, which is itself a living process, breaks up the organic compounds in the bodies of larger plants and animals and makes the elementary substances again and again available as raw materials for living bodies.

Plants and animals are related in continuous food series, or "chains".

There is a numerical relationship between the members of one species and those of other species in the same food chain.

[1]See No. 5, p. 577.

Deserts, prairies, mountain ranges, tundras, forests, oceans, rivers, and the like each obstruct the migration of certain species, and at the same time further the distribution of others.

In any area the composition of the population changes through the arrival of new species which happen to fit the conditions brought about by their predecessors and which make, on the whole, better use of the existing situation.

Through the interactions of plants and animals with each other and with the soil, water and atmosphere, the composition of a population gradually reaches a point which represents the optimum, or climax, for a region.

The many different interdependent species in a region make up what is called a natural community.

As man subordinates other forms of life to his purposes, he sometimes destroys the very species upon which he depends for his further existence.

As in the natural community, a growing human community makes it possible for new types to flourish; the pioneer becomes relatively inefficient in every job he is capable of doing and so is replaced by interdependent specialists of many and diverse kinds.

EXPLORATIONS AND PROJECTS

1 To study the way in which earthworms mix and aerate the soil, place between two vertical panes of glass an inch apart a layer of rich loam and above it a layer of coarse sand. Introduce earthworms and observe for several days. (Keep soil relatively moist, though not wet.) Describe what happens to soil and sand and explain how this is related to the growth of plants.

2 To investigate food chains, start with any species of animal that is convenient and find out (*a*) upon what species it feeds and (*b*) what species feed upon it. Extend the chain in both directions. That is, after each species in list *a*, enumerate in order the species that supply it food, tracing as far back as possible; and similarly, after each species in list *b*, enumerate in order the species that use *it* as food, again tracing each line as far as possible. The food chains and food cycles of such organisms as a lady-bird beetle, an earthworm, a swallow, a crustacean, or a zebra would be interesting to investigate. Represent your findings diagrammatically.

3 To work out the food chains in a restricted habitat, find what organisms dwell in it, and so far as possible determine what eats what. In such a habitat as a decayed log one can study various relationships among fungi, sow bugs, millepedes, spiders, caterpillars, ants, aphids, termites, protozoa, bacteria, seedlings, birds, centipedes, snails, slugs, etc. Record and interpret your findings.

4 To become familiar with various habitats, visit a varied stretch of countryside, identifying different habitats, along with the dominant forms of life found in each. Some interesting kinds of habitats to study are a moist woodland gorge, a pine wood, a deciduous forest, a cypress swamp, a floating sphagnum-moss bog, a riverbank, a seashore, a sand-dune, a second-growth brush, a meadow, a barnyard, a mountaintop.

Record your findings. Draw conclusions concerning the specific conditions which favor the growth of plants in the distinct habitats which you visit.

5 To contrast the topsoil in a forest and in a run-down cultivated field, select two locations similar in all other respects, and examine the soils. With a spade dig a hole through the topsoils in each case. Determine how they compare in depth, in proportion of organic material to sand and clay, in water-absorbing and water-holding capacity, in amount of decay that is taking place, in compactness, in resistance to erosion, and in other features. Record your findings. Relate what you have found with reference to the effect of forests upon fertility and upon floods.

QUESTIONS

1 What kinds of living things can be entirely independent of other organisms?

2 Why cannot all living things be entirely independent of others?

3 Why are there more parasites among microbes than there are among the larger plants and animals?

4 Why is it important to distinguish between symptoms and causes of diseases? Why is it important to know the symptoms and the causes of diseases?

5 How can the abundance of a particular species of plant or animal (reindeer, oranges, whales, cotton, sugar cane, sheep, cattle) influence the whole mode of life of a community?

6 How may certain physical features act as barriers to the spread of some species, and at the same time aid in the distribution of others?

7 In what ways are conditions in a pioneer community like those in a climax community? In what ways different?

8 What factors bring about the normal shift within a community toward the climax grouping of organisms?

9 What are some of the advantages of carrying the division of labor still farther among individuals? among nations? What are the disadvantages?

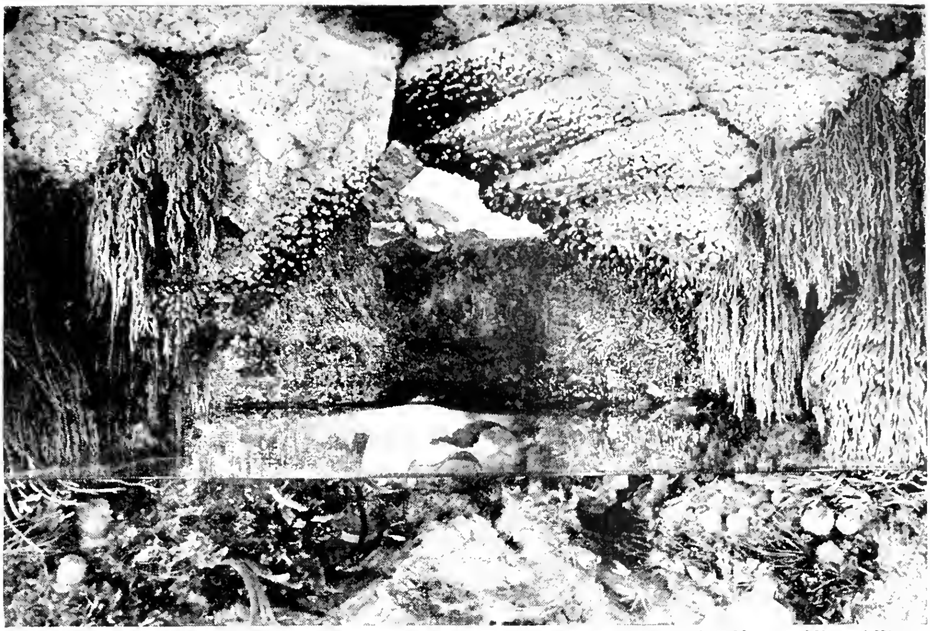
10 Is a person with a special talent better off in a large community or in a small one? Why? How about a person with a special handicap?

11 In what respects are human communities like those found in nature? In what respects different?

1 If living things are in balance, how can the population of any species increase?
2 Why are there more insects or fish in some years than in others?
3 How can a species thrive as well in a strange region as it does in its natural or original home?
4 Does introducing a new species into a region always cause harm to others?
5 Does any harm result from exterminating any species?
6 How have some species been exterminated?
7 Can species change their feeding or other habits to fit a new set of conditions?
8 Are there any regions that once had much life but now have little—or vice versa?
9 Does increasing the amount of life in one region have to reduce the amount in another?
10 Does growth of human population mean that other species are reduced in numbers?

We keep a young child away from complicated machinery because there is danger he might get hurt poking among the moving parts which he does not understand. Another reason is he might injure the machinery, or start something that might lead to even greater disaster. When we poke about in this complicated world of plants and animals, we are not always aware that we may be starting trouble. Shooting blackbirds for fun may mean merely shooting blackbirds. But it may mean advancing the price of bread in far-away cities next autumn. For while each hunter may kill only a few birds, the sport may turn the scales between locusts and wheat. Neither the hunter nor the housekeeper buying bread far away may know what birds here have to do with the price of bread there.

Living for generations in a particular locality, people learn pretty well what plants and animals they can afford to encourage or to destroy. As we move rapidly into strange regions, the task of maintaining a balance of life becomes increasingly difficult. This is not so much because the problem becomes more complex, for we can construct and operate very complex machinery: we can learn which lever or button to press for desired results. But when man interferes with natural processes, he cannot always be sure what he is setting loose or what he is bringing on. And yet we have to interfere. Living means interfering with nature. Is it possible to upset the balance without bringing about undesirable results? How can we tell how far it is safe to go?



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ADJUSTMENT TO EXTREME CONDITIONS

Inhabitants of this tide pool or of the ocean shore must be tough to stand the beating waves and the rushing tides. Twice daily they are exposed to the drying air and then submerged again. The surrounding conditions are of many kinds, but the organisms survive the variations, which are fairly regular, or periodic, and limited in degree

How Is the Balance of Nature Upset?

Life Is Always Upsetting When a plant-animal community has reached a fairly stable "climax", it contains the greatest amount of living matter that the particular region can sustain. This situation is similar to that in a balanced aquarium with green plants or in a "ripe" hay infusion. Such a condition of balance is like the resting position of a pendulum or of a scale-beam—it is easily upset, by a comparatively slight disturbance.

The balance of nature, however, is not a state of rest. It is more like the continuous swinging of the pendulum back and forth, within certain limits. We might perhaps better speak of the balanc*ing*. For the condition in a forest, for example, or in a tide-pool is one of continuous change (see illustration above). And it is also one of continuous *ex*-change. Materials move from the air and soil into green plants, from plants to animals, and eventually back to soil and air.

The relative numbers of the different species may remain essentially the same indefinitely, though they do, of course, fluctuate from day to day and

from season to season. Plants grow but are constantly destroyed by other plants and by animals. Baby sunfish increase in size, while the insect larvae on which they feed diminish in numbers. They themselves diminish in numbers, while a perch grows at their expense.

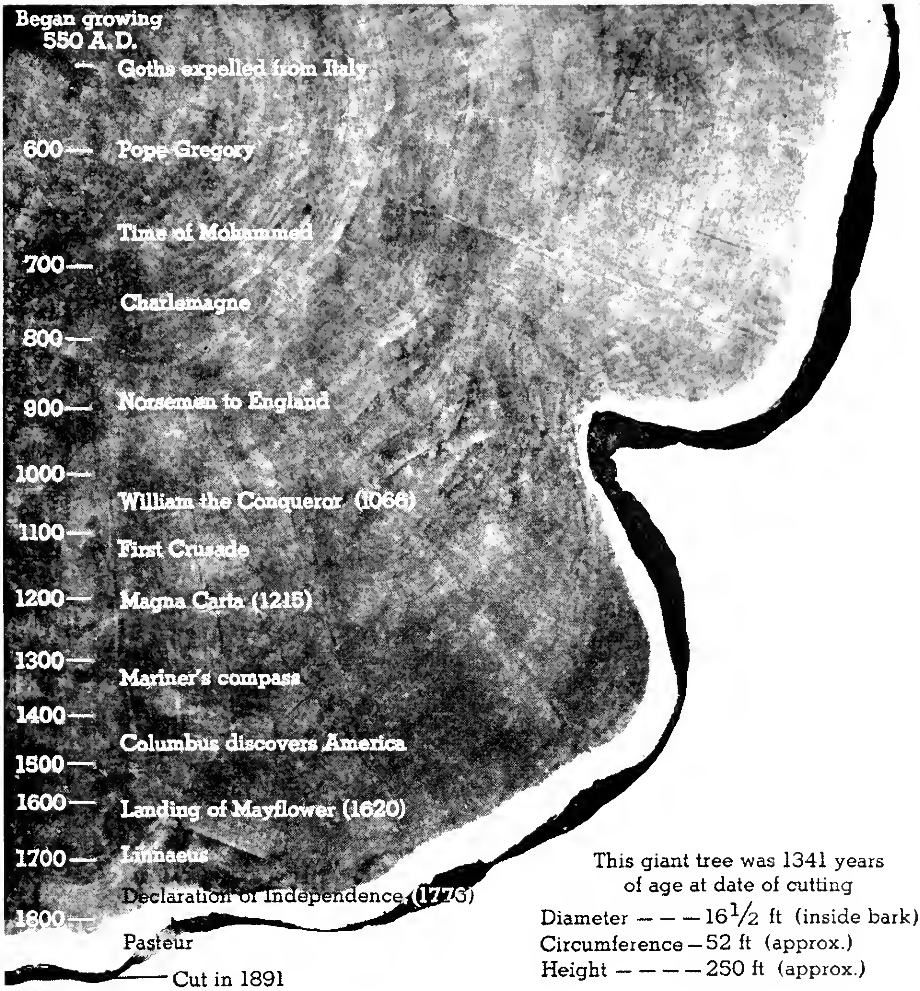
At the end of a good growing season insects and worms and birds and rodents, as well as plants, will be more numerous than after a poor growing season. That in turn will mean a prosperous year for hawks and foxes and other carnivorous animals. Later on various fungi, worms, beetles and bacteria will be exceptionally numerous. A species expands to the limit of exceptional abundance only to furnish a stroke of luck for those who depend upon it. There is no endless up and up; life is a succession of ups and downs. Even in the steady growth of an old tree we can find indications that its "fortune" has fluctuated with changes in the amount of sunshine (see illustration opposite). These records are so consistent that it has been possible to ascertain the dates of timbers in ancient structures through them. And it has been suggested that human affairs might be profitably studied in terms of the changing abundance of plant and animal life in the past.

Food and Elbowroom Experiments with flour-beetles and other insects show that in a given area the number of individuals never increases past a certain point regardless of the amount of food. A colony of bacteria in a food medium will grow only so far and then stop, long before exhausting the food. Apparently there is a point beyond which more and more food does not mean more and more growth—for a particular individual or for a colony of individuals or for a species.

In a given field a thousand seeds of corn or of tomato will start more plants than five hundred seeds. But five hundred may produce a greater number of mature individuals and a greater yield. For spacing and air are quite as essential as root-hold. With human beings food is a first condition for growing and multiplying, and elbowroom is a close second. And yet the race appears to have multiplied more rapidly where the density of population is already highest. In slums of industrial cities and in parts of India, for example, the birth rate is higher than in other parts of the community. Yet in many such places the death rate exceeds the birth rate. People continue to live there only because new individuals and families are constantly being pushed in from outside. Such crowding of one species offers very favorable opportunities for other parasitic or predatory species.

Epidemics People in past ages looked upon epidemics of disease or of pests exactly as many of us today look upon an unexpected hurricane or earthquake. They just happen. In the quaint language of insurance company lawyers, they are described as "acts of God"—without necessarily implying either any theory as to how things come to happen or any theory of religion.

Today we do have definite theories about how epidemics come about, and



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LIGHT AND LIFE

Variations in the rings of a tree's wood evidently correspond to yearly variations in conditions favorable to growth. But these variations appear to be periodic; and the rhythm corresponds in a remarkable degree to the rhythm of sunshine intensity, which in turn is related to the sunspot cycle of about eleven years

we are so much better prepared to deal with them. If the scale-lice, for example, cover the twigs of a tree in a thick layer, the ladybird beetles will devour them voraciously, and then multiply very rapidly. The happy and prosperous plant lice are all but wiped out. Their very prosperity has invited an epidemic of their enemies. An epidemic may in fact be considered as a very prosperous opportunity for some plant or animal that unexpectedly gets into a crowd of its potential hosts or victims.

To the parasitic and predatory organisms the situation is an exceptional period of prosperity and expansion. For the victims, however, it is an epidemic, a visitation of misfortune. On the other hand, a period of prosperity and expansion is likely to be followed by a period of privation, as, for example, with the ladybirds who have all but exterminated the scale insects in a region. Moreover, long before most of the prosperous and abundant little beetles have a chance to suffer from famine, they will have furnished a feast for various birds and their babies.

An epidemic usually comes to an end abruptly because the successful species has destroyed its own food supply. In the case of insect or fungus pests, an epidemic—that is, an unusual crowding—invites another species to take advantage of the unusual abundance of food. In the long run the victor *becomes* the spoils.

How Has Man Disturbed the Balance of Nature?

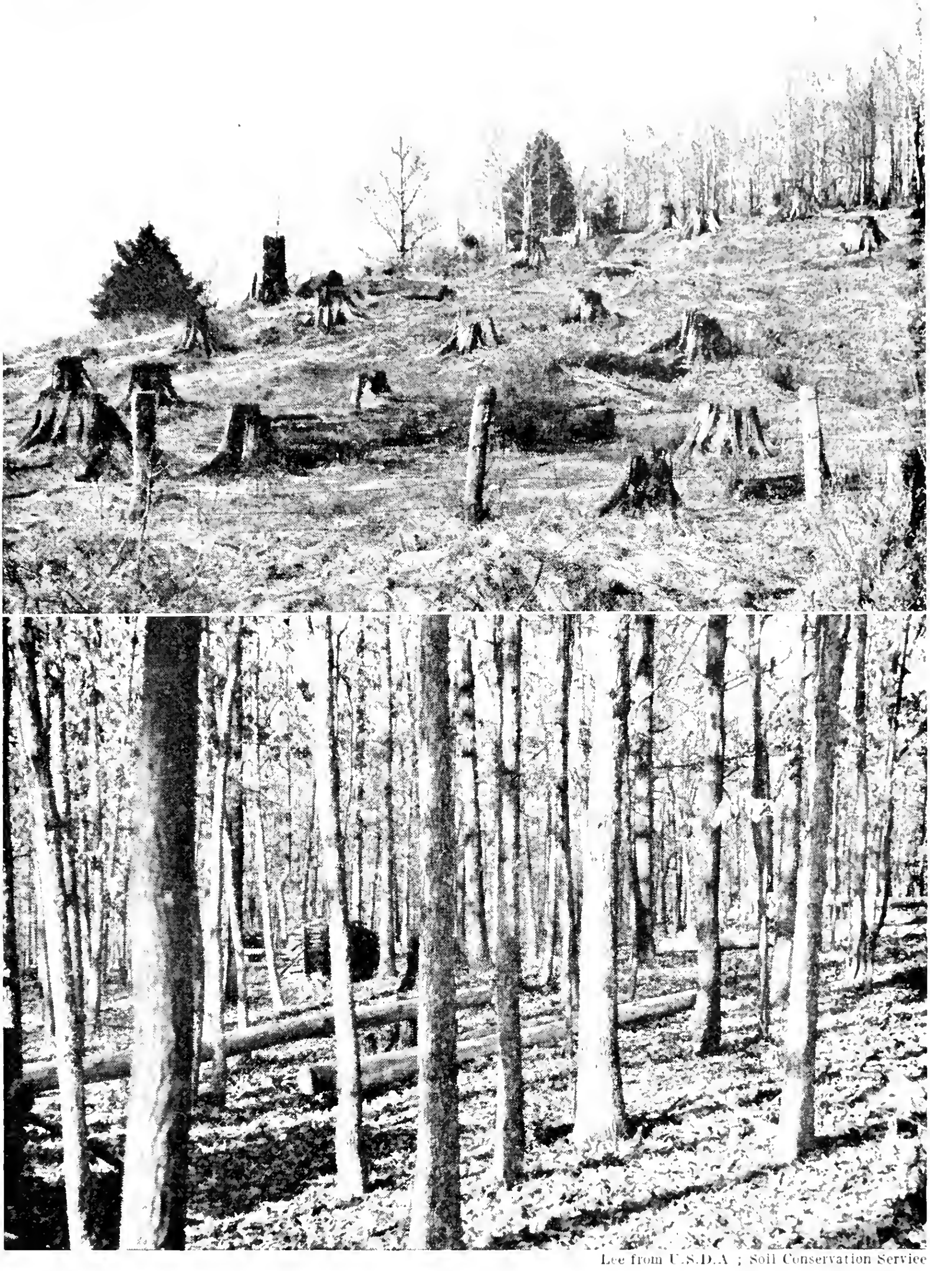
Man's Intrusion[1] Long before the dawn of history man had domesticated the dog and species of ox, sheep and goats. He was able to maintain a steady food supply. The family was enabled to enlarge, and to stay in one place for a relatively long period. Herdsmen did, of course, have to move when rains failed or when their cattle ate up all the grass in the neighborhood. But the nomads were more orderly in their rovings than hunters. Living generally became better organized.

From being a hunter to being a herdsman man took a step forward. From being a herdsman to settling down as a soil-tiller, he took another step forward. The gains may be measured by the fact that population grew. The domesticated plants and animals multiplied in numbers. But man's success threatened to upset the natural balance. Increasing the population of men and of domesticated species furnished their enemies and parasites exceptional opportunities. Flies and liver-flukes increased rapidly. Man has invited to his farms all kinds of vermin, insects, fungi and worms that had previously lived on the sparse vegetation or animals of the natural life-community.

These changes in man's mode of life meant more intensive hunting of birds and game and fish. They meant changing the composition of the streams into which he threw his refuse. In proportion as man has thrived and grown in numbers, he has made increasing demands upon the earth and has exerted increasing pressure upon other species. Concentrating population—human, vegetable, animal—brought about the destruction of some species and the increase of others.

Mining Wood Man could find an opportunity to live only in a region at or near the climax of its development (see page 568). The forest has been

[1]See Nos. 1 and 2, p. 598.



Lee from U.S.D.A.; Soil Conservation Service

TWO WAYS OF LUMBERING

In irresponsible lumbering as much wood was allowed to rot and to burn as was actually removed for practical use as timber. In scientific lumbering, selected trees are cut clean, close to the ground; branches are trimmed and the underbrush is cleared away. More timber is used, and all of it is replaced by new growth

most favorable for man, as for other mammals. And man's use of the forest well illustrates the effects of his interference with the balance of nature. The settlers cleared land as rapidly as possible to make room for farms and homes. Much of the wood they used to construct shelters, barns, fences, bridges. Year by year, however, as the population grew and extended westward, forests became the source of valuable material which needed merely to be cut and shipped. They were treated like mines that would last forever.

In the first hundred years after the formation of the Union, timber was so recklessly cut that millions of acres of forests which had taken centuries to grow were destroyed. Since a virgin forest is a well-balanced living community, its growth is at a standstill. New growth is just enough to offset the death and destruction among old trees. When man invades the forest, not only does he remove wood faster than the new growth can replace it, but he destroys also the shelter and food upon which birds and mammals normally depend. As a result, the weeds, insects, and other small animals upon which these birds and mammals feed begin to multiply at a rapid rate, so that the entire community is thrown out of balance.

Man and Birds Like most animals, birds are important to us chiefly because of the food they eat. But unlike insects, for example, birds in their feeding are usually of advantage to mankind. Many birds have been convicted of eating fruit in the orchards. And it is true that the sharp-shinned hawk has been caught carrying off young chickens from the barnyard. Nevertheless, with a very few exceptions, the common birds are worth more to us alive (as destroyers of insects, vermin and weeds) than dead (as sources of feathers or food) or as objects of sport.

We cannot class each species of bird as altogether useful or altogether injurious. The red-tailed hawk feeds on field-mice in one region and discovers that chickens are good to eat in another. The bobolink is a serious menace to the rice fields in the South, but is a valuable insect destroyer in the North. The red-winged blackbird ate so much grain in Nebraska one year that the farmers took up arms and killed the bird off. The following year, however, the absence of the blackbirds enabled the locusts to multiply so rapidly that many of the grain crops were ruined.

In Pennsylvania, in the 1880's, the state legislature voted a bounty for killing hawks and owls, which were supposed to be killing chickens. In less than two years nearly $100,000 was paid in bounties. Biologists who studied the situation in detail found that the predatory birds might have killed chickens worth a few thousand dollars. But they found further that the mice which birds did *not* kill damaged the crops to the extent of $4,000,000. The law was repealed.

Destruction of Birds Many birds are destroyed wantonly by ignorant boys and men. Some are killed to supply feathers. Still others are exter-

United States Forest Service

BEFORE AND AFTER MINING LUMBER

Hillsides stripped of native forest cover soon become denuded of soil. Afterward the barren, unproductive soil may be deposited on fertile valley lands during floods, destroying their productivity as well

minated when their eggs and nests are destroyed out of idle curiosity or in the interests of untrained collecting. In rural and suburban districts domestic cats have probably done far more damage to the native birds than they paid for by killing mice or rats. It is an open question whether we should not be better off in most cases without the cat.

During their migrations many birds are killed by flying against telephone and telegraph wires and against plate-glass windows. Along the shores, migrating birds frequently hover about the lighthouses at night until they are exhausted. The clearing of forests, the extension of cities, and the improvement of farms all lead to the extermination of various species of birds. Destroying dead limbs and dead trees in forests and woodlots may drive out the downy woodpecker and the redheaded woodpecker. But it is worth while to keep the woodlot clear.

There is no evidence that poison sprayed on trees to destroy caterpillars ever injures birds. Even if this did sometimes happen, however, we should have to continue spraying, for as we cultivate more plants, the insects that feed upon them multiply too rapidly for the birds to keep in check.

Protection of Birds Many of the destructive agencies that affect birds are directly under our control. Gratings placed on certain lighthouses off the coast of England enabled countless thousands of migrating birds to rest in their flight, instead of dashing themselves to destruction against the lights. As electric, telephone and telegraph wires come generally to be placed underground, as they are now in the cities, birds come to have a chance to fight it out with their natural enemies and the natural obstacles to their survival.

Men and boys will have to learn to find sport in opera glasses or the camera, as women and girls are learning to be happy without bird's plumage or to be content with the dyed feathers of domestic fowl. It is possible to get as much fun out of building nest boxes and shelters for birds as out of shooting or trapping them. Birds encouraged to make their homes in our immediate neighborhood will continue to furnish us with interesting sights and sounds long after dead birds would have been forgotten. In addition to providing suitable boxes for birds' nests, we may scatter grain or bread crumbs after heavy snowfalls and so enable many birds to survive until the ground is clear and they are again able to find food for themselves.

The red squirrel often destroys eggs and sometimes even young birds, but does nothing to compensate for this damage. These animals should therefore be killed, to give the birds a better chance. The weasel, the skunk, the fox, the raccoon, and other mammals sometimes kill birds or eat their eggs; but as they do not feed exclusively or largely upon birds, they are not to be considered serious enemies.

Migration When food is scarce in any region, it is "natural" as well as intelligent for man to move away. Plants that propagate vegetatively may

New York Botanical Garden

MIGRATING FROM A CENTER

This "fairy ring" of mushrooms (Lepiota) on a ranch in Colorado suggests how a vegetation or population, fixed to the earth, moves outward as it exhausts the food available

often be seen moving away from a center in all directions, and in ever-widening circles (see illustration, above). Man, along with other species, has pushed out into new regions not only to find more food, but to escape enemies. Indeed, many of us today move from one place to another for our health. The particular climate, the presence of particular plants or animals, may make our present location unsuitable—for some of us. Again and again people have moved in hordes from regions considered unwholesome and regions invaded by pests.

But in moving away the individual or horde becomes an interloper. Every new arrival disturbs the existing "balance" and threatens to drive some of the plants and animals away or to destroy them. Men moving in large numbers are like a swarm of locusts moving across the land and destroying every scrap of vegetation. In a comparatively short time European man has driven from their former habitations the Indians who had lived in North and South America for centuries. He has reduced to a small fraction of their former numbers many species of wild mammals, birds and fishes. He has destroyed the trees on millions of acres, practically all the grasslands, and the fish in hundreds of miles of stream.

To offset the destruction, man has made millions of acres bear vastly greater quantities of particular kinds of vegetation than would have been possible under natural conditions. The corn, the potato, the tomato, the tobacco, the peanut, the strawberry, had inhabited this continent long before the white man came. But never had any of these species thrived so luxuriantly and so

FORMER INHABITANTS

Beavers, foxes, bears, minks, antelopes, moose and elk are very rare today. Wild turkeys, passenger pigeons, and heath hens are gone, with the buffaloes of the plains. Such bison herds as the one pictured above are protected in national parks

abundantly as they have done under man's care and cultivation. These plants, as well as other species imported from various countries, have taken the place of dozens of species that might otherwise have thrived on this area under "natural" conditions.

Transportation Man, moving with his household effects and his cattle and his seeds for future planting, carries with him all the vermin, all the destructive parasites of his household and his associates. Europeans traveling to the islands of the Indian and Pacific oceans brought with them infectious diseases that turned out to be very destructive to the natives. The whites, in turn, succumbed in large numbers to tropical diseases. Negroes brought as slaves to America in the eighteenth and nineteenth centuries carried with them an internal parasite, the hookworm, which they seemed able to tolerate without serious discomfort or privation (see page 615). Later, however, when this hookworm became established in the soil of our Southern states, the parasites infested large sections of the white population, with disastrous effects. Conversely, measles and other diseases long familiar to the white population attacked the Negroes with exceptional severity.

From these examples we see that a parasite moving into a new region may find a host that is incapable of defending itself, and the parasite thrives. Or a species enters a new region and becomes the prey of parasites against which it has no defense. Or an invading species may be particularly destructive because it finds suitable food but does not run into its old enemies.

Soil Conservation Service

CROPS NURTURED BY MAN

Man makes wheat grow where formerly buffalo grass thrived; but only by constant care and management. Wheat never grew so luxuriantly by itself; yet how quickly would it be replaced by other grasses should man cease his nurture!

We saw that rabbits, introduced into Australia, became a pest (see page 564). They interfered not only with the native wild animals but with agriculture and sheep-raising. Bounties were paid to encourage the destruction of the rabbits. The water-cress was similarly introduced into New Zealand, and in a comparatively short time it choked all the rivers. Elodea and the muskrat were brought to England and multiplied much more rapidly than they had done in their older habitats. The English sparrow was brought to this country to destroy the tent caterpillar, which was injuring shade and orchard trees. The sparrows took to living in the cities too, feeding largely on the undigested seeds in the droppings of horses. By the end of the century they had become a nuisance. They were not helping to fight the insects, and they were interfering with other birds. They have been gradually disappearing from our cities, however—but not because we have done anything to discourage them. We replaced our horses with automobiles, which yield no by-product that sparrows can use.

Mining versus Cropping Man was intelligent enough to devise weapons and tools which enabled him to kill and destroy out of all proportion to his actual needs. Using his excess power, he changed the balance among living species in the areas he occupied. In his hurry to get a quick profit from the forest while the getting was good man not only destroyed the forest, but exterminated game and fur animals and birds. He brought about far-reaching changes in the soil and water relations of areas stretching across the states.

By "mining" the living resources of the earth instead of husbanding and cultivating them, we have produced ugly, desolate holes. We have replaced luxuriant and balanced life-communities with scavenger and decay organisms. The results of his handiwork force man to move on. Only as such results accumulate have we gradually come to recognize the danger of some day pushing ourselves off the earth. To keep ourselves going, we must keep the earth continuously fertile and fruitful.

How Can We Meet Our Needs without Destroying the Sources?

The Conservation Idea[1] Those who enjoy hunting and fishing, or who sell what they kill or catch, find it very difficult to see why anyone should want to interfere with their sport or business. After all, hunting and fishing are very ancient vocations and very ancient modes of enjoying life. There were hunters before there were farmers and long before there were foresters and game wardens. Present-day hunters and fishers feel close to nature and close to "natural law". But modern man, having learned to write and to figure, is able to look ahead more than a lifetime and backward more than a generation. He is able to calculate the danger of trying to live like a hunter and fisherman in a world of growing populations, automatic machines, airplane transportation and radio communication. It is impossible for the earth to maintain its present population (to say nothing of the future) on the simpler basis (see pages 534–535).

Forest Control[2] Before the beginning of the present century it became evident that we were destroying forests faster than they could grow. There was a movement for conserving the forests, for introducing more economical methods of using the natural but limited resources, and for developing methods to replace with new growth what was removed each year. This movement met with much opposition. Those who agitated for conservation were easily discredited as cranks. Every effort to protect the public's interest in the forests as a national resource was denounced as interfering with private business.

Theodore Roosevelt, during his Presidency (1901–1909) supported Gifford Pinchot in his attempt to educate the public, as well as forest-owners and forest-operators, to a more scientific—and in the long run a more productive—policy. Research and practical development since then have made more and more people recognize that the forest is something more than a lot of trees that happen to be on somebody's acres for him to use as he sees fit.

We all depend upon the products and the inhabitants of the forest, as well as upon the water and soil that are influenced by the living trees. Control of the forest, therefore, becomes a matter of national concern. In the past, pri-

[1]See Nos. 3 and 4, p. 598. [2]See No. 5, p. 598.

vate owners of forest land cared only for what they could get out of it. We could not expect them to feel much concern about effects a hundred miles or fifty years away. We therefore could not depend upon them to handle forests so as to assure the general population full benefits and necessary protection.

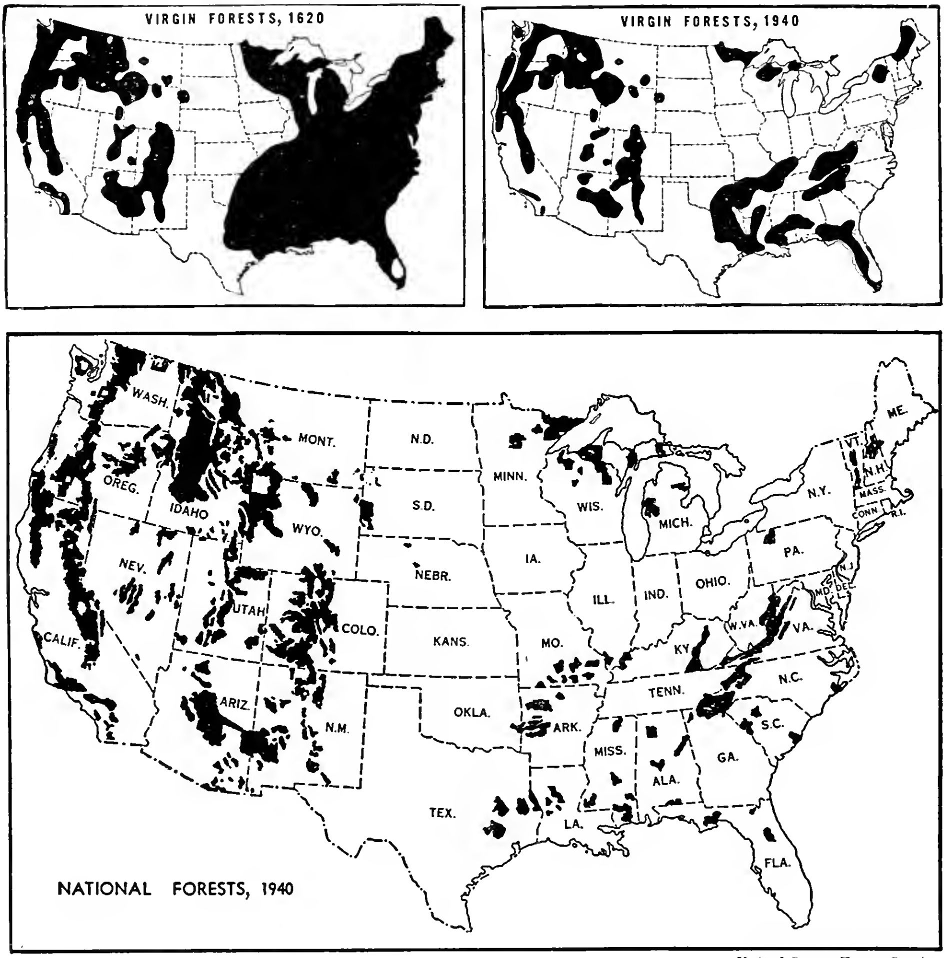
The Forest Service The Forest Service of the United States Department of Agriculture, which was established in 1875, has made many careful scientific studies of forest conditions in different parts of the country. It has thus been able to give sound advice on the care and management of forests and wood-lots from every point of view. From these investigations we learn, first, how to protect forests against certain injuries and, second, how to increase their value. We now know that it is possible to get all the wood we really need without destroying our forests, if only we follow certain principles.

Over one hundred million acres of land have been left barren by "timber mining" and fires. The reforesting of such areas is continuously under way in many parts of the country. A great deal of worn-out land and sand-dune land is well suited to forests. In many cases it is necessary only to protect the young growth from fires. Another method of extending the area of growth is to stock existing forest lands more fully.

Increasing Yield and Quality It is likely that not more than from seventy to one hundred of the nearly one thousand native species of trees in this country are worth growing, from the economic point of view. The red cedar grows very slowly; the white pine or the red oak could be grown in the same soil to great advantage. We could replace the red spruce in New England with the Norway spruce, just as many areas of France denuded by the First World War, as well as other European regions, have been restocked with Douglas fir imported from this country. In some localities we may perhaps find foreign trees better suited to our purposes than the native trees. In the course of a number of years the rapid-growing varieties will yield much more timber than the others. But rapid growth is not of itself a deciding factor, for it is necessary to consider the toughness of wood and other qualities. The whitewood, or tulip tree, for example, grows much faster than the oak, but it can never be used as a substitute for the oak.

Without increasing the amount of growth, the value of timber can be increased through efforts to keep the trunks and branches straight. By thinning out the crooked or twisted trees, it is possible to concentrate the growth in the best trees and so to increase the yield of a forest area.

Avoiding Wood Waste In the national forests lumbermen are given practical demonstrations of scientific cutting, seeding, reforesting, etc., and also of the economical handling of growth. In careless lumbering, a tree is sometimes damaged while being cut down, and trees left standing are sometimes injured. At the forest-products laboratories and the forest experiment



United States Forest Service

FOREST AREAS IN COLONIAL TIMES AND TODAY

It is estimated that in 1620 the forest area was more than 800 million acres. By the beginning of the present century we had less than 500 million acres. This has gradually been increased to over 600 million, nearly a third under public administration or control. And increasingly our forests are being operated for continuous yield

stations investigations are constantly being made to find the best methods of utilizing wood and other forest products for various purposes, as well as of getting optimum yield.

Forest Dangers The person who cuts recklessly and destroys for immediate profit what ought to last practically forever menaces our forests. This enemy can be regulated either by enforcing strict rules as to the private management of forests or by making it impossible for individuals or corporations to profit from the exploitation of forests.

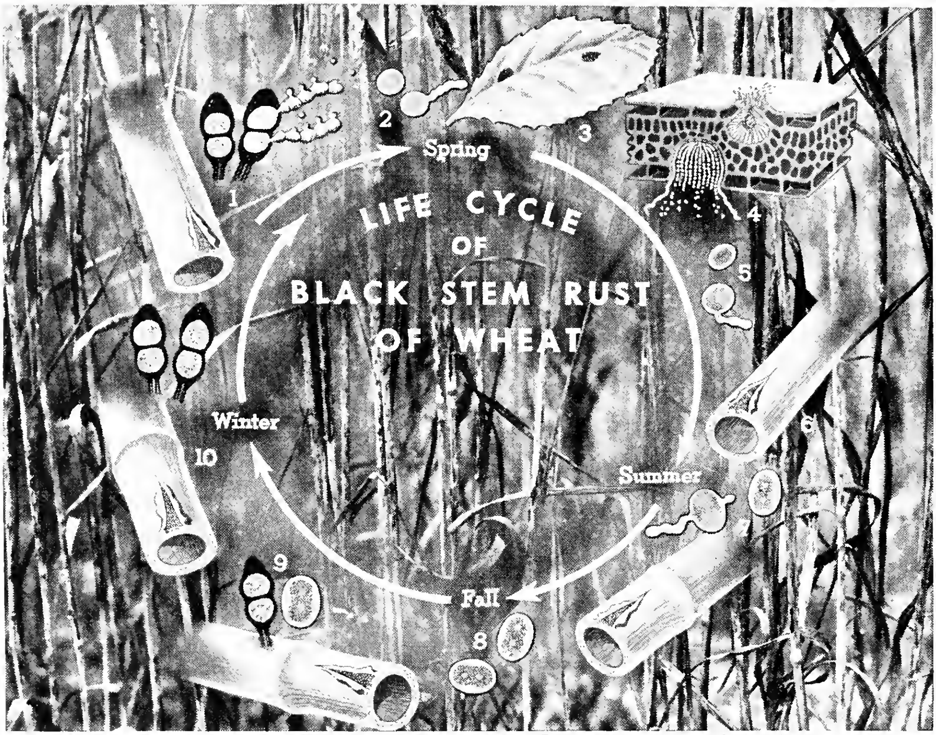
Fires, most of which are of artificial origin, annually destroy much of our forests. In the unprotected areas the damage, measured in acres burned, is proportionately sixteen times as great as in the protected areas. Well-organized fire patrols in the national forests have succeeded in preventing many fires and in keeping the total fire damage down to a small fraction of what it is in the privately owned forests. The chief damage done by forest fires is to young growths; this prevents restocking. The rules for fire prevention in forests are posted on trees, and every person who has occasion to go into the woods should heed these regulations.

Important but less serious dangers to forests are various species of insects and various species of fungi. Every year these organisms destroy trees and timber worth millions of dollars, and there is no one way to fight them all.

Hand-to-Hand Fighting One way of dealing with pests is to go after them directly when they show themselves. We slap every mosquito that alights on our skins. We swat flies or pull a tomato worm from the vine. We pull up weeds. Somehow weeds, flies and other pests seem to multiply faster than we can pull them up or kill them. We look for wholesale methods. We set traps to catch the enemy in large numbers: traps for rats and mice, for Japanese beetles, for houseflies. These can work while we sleep or are otherwise engaged. We place poison where we think it will do most good—for mildews and for insects and other species.

Barriers Where the enemy is known, we are often able to put up barriers against his depredations. We may fence in our cattle against wolves or quarantine them against infection, just as we screen our houses against flies and mosquitoes. But keeping the enemy out is not always practicable, especially when we do not know the enemy well enough. For after all, how does the liver-fluke get into the sheep? How do cattle "catch" Texas fever? How does the worm get into the apple? A large part of the research work of the United States Department of Agriculture since the time of Lincoln has had to do with learning the life histories of insects and other parasitic or predatory animals and plants. These studies reveal to us not only the weakest link in an organism's life cycle, but also the weakest links in the food chains of which the species may be a part.

According to such studies we find that when we cannot shut all the possible gates against an enemy, we can sometimes stop him in his tracks. By destroying the barberry bushes in the regions that grow wheat, we make it impossible for the wheat-rust fungus to complete its life cycle. In the case of the liver-fluke, we find the key in ponds that harbor certain snails: no snails in the pond, no liver-fluke in the sheep (see page 615). The alternate host of the white-pine blister is the wild currant or the gooseberry. The most familiar example of breaking the life-chain to control a pest is perhaps the case of the mosquito. By draining swamps, covering rain-barrels, oiling ditches, we



After Bureau of Entomology and Plant Quarantine, U.S.D.A.

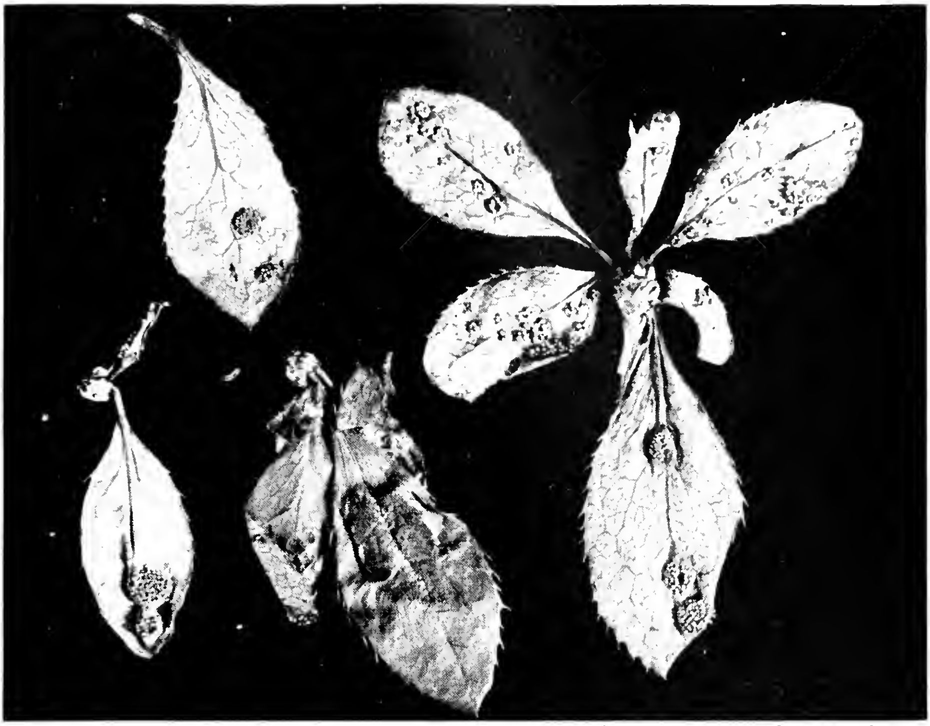
A DOUBLE-FACED ENEMY

The destructive black stem rust of wheat spreads rapidly through the summer by means of spores, in two or three successive generations. The two-celled spores that survive the winter cannot infect wheat. In the spring these spores produce short hyphae, which bear multitudes of rather tender spores, which are also indifferent to wheat

eliminate mosquitoes, which depend upon wetness for their early stages—egg, larva and pupa. And in doing so, as we all probably know, we interfere with the continuity of the malaria parasite or of the yellow-fever virus (see table, p. 620).

Fighting Fire with Fire Biologists have found that a most effective way of fighting an epidemic is with a counter-epidemic. Thus, since a troublesome species is probably kept in check in its native habitat by its natural enemies, we can restore a disturbed balance by finding the natural enemy of our pest.

It has been possible to control the destructive Hessian fly by means of the parasitic insect *Polygnotus*. The gypsy moth has been a constant source of destruction to various cultivated crops since about 1870; it seems to be coming under control with the introduction of the calosoma beetle from France (see illustration, p. 596). One of the first suggestions that insects could be



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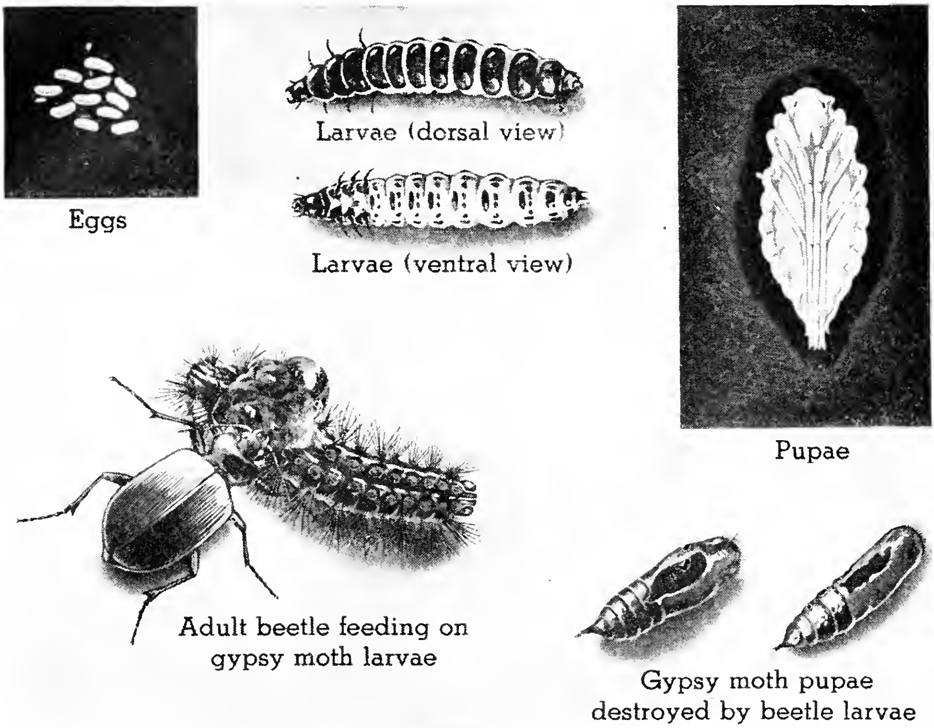
AN INNOCENT-LOOKING HIDEOUT

The new spring spores of wheat rust attack the young leaves of the barberry. By destroying the barberry, we are able to control the black stem rust of wheat, for the rust dies out during the winter months. The species has no way to keep going unless both its hosts are present in the same area

controlled by encouraging other insects was made in the early part of the last century by two English entomologists. They declared that the aphids, or plant lice, which did great damage to hops, could be cleaned out of the greenhouses and fields by increasing the number of ladybirds (see page 581).

Since 1916 the Japanese beetle has been spreading destruction to more than two hundred and fifty varieties of crop, garden, and orchard plants in twenty-two states (see page 655). After years of search in Japan and Korea agents of the United States Department of Agriculture found two natural enemies of this pest that promise to help check its injurious career. One of these is a genus of antlike winged insects. The female burrows in the ground, where the beetle larva destroys the roots of plants. She stings a larva and paralyzes it, and then lays an egg in it. As the young parasite hatches out of the egg, it feeds upon the larva and destroys it. The other promising natural enemy of the beetle is a spore-bearing bacillus that produces a fatal disease in the larva. The bacteria multiply in the blood of the insect and turn it into a



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ENGAGED TO FIGHT OTHER INSECTS

This beautiful green calosoma beetle (Calosoma sycophanta) was used by a French scientist in 1840, in a campaign against the gypsy moth (Porthetria dispar). In recent years this method of combating undesirable insects by encouraging the spread of their natural enemies has been rapidly developed

milky fluid. Dead larvae, the skin containing now millions of spores, are dried and ground to dust, and mixed with an inert powder. The mixture is distributed on the soil of an infested area, and the larvae become infected.

Other insects have been successfully combated with parasitic bacteria and fungi. In South America and in Yucatán this method has been used against locusts. Quantities of the insects are caught alive, infected with the parasitic fungus, and then set free again. The escaped animals transmit the infection to their fellows, and millions are killed off. One epidemic is made to overcome another, until a balance is restored.

Man the Disturber Man has been extending his domination over the earth at an ever-increasing pace. He has succeeded not by growing stronger muscles, longer teeth or sharper claws, but through his scheming, planning, devising, manipulating. He began by handling sticks and stones that he could pick up. These enabled him to exert power and to produce effects at a dis-

tance. He has gone on to rearranging the very face of the earth, to rerouting its rivers, to altering the character of its plant and animal life. He distributes species and changes the relative numbers of various species, all to serve his needs and his desires. But in extending his domination, man sets up processes the remote results of which he cannot possibly anticipate. Who could have foreseen that placing a paper factory at one point along a river would ruin the life in the river or the water supplies of cities far away? Who could have guessed that making fine wheat and cotton grow in rich crops in place of the scrubgrass would end by destroying the soil itself?

When we undertake to change the numbers of any species, it is not enough to know that a particular species is useful or harmful. We have to proceed cautiously, and seek as thorough a knowledge as possible of all the relationships in which each species is involved. Nor is it a simple matter, as many assume, of "interfering with nature's plans". Nature's "plans" include man and life, and life is always interfering. It is a matter of altering certain slowly moving processes of mutual adjustment, certain *balancings*, so that we can fit ourselves into them while advancing our own welfare.

In Brief

Within a balanced community of living things, the essential ratios and relationships of the different species remain fairly constant.

Each wave of abundance for any species lasts only until the organisms have expanded to the limit of the resources.

Within any living community there is a point beyond which more food does not mean more growth, for other factors limit the results.

An epidemic may be considered as an exceptionally favorable opportunity for some plant or animal that finds itself among a crowd of its potential hosts or victims.

In proportion as man has thrived and grown in population, he has made increasing demands upon the earth and has exerted increasing pressure upon other species.

By making many plants and animals of the same kind live close together, man has brought on a constant succession of epidemics.

With every migration, the new individual becomes an interloper; every new arrival competes with plants and animals in an existing balance and threatens to drive some away or to destroy them.

A parasite moving into a new region may find a host that is incapable of defending itself, or it may become the prey of a species against which it has no defense.

Invading species may become particularly destructive if they find an abundance of suitable food and no natural enemies.

By destroying forests, man exterminated much of the wild life and brought far-reaching changes in the soil and water relations of areas stretching across states.

Increasingly, our forest areas are being operated for continuous yield.

By concentrating our forest growth in the best trees it is possible to increase the yield of a given area.

The four most serious dangers to the forests are ruthless cutting for profit, fires, various insects, and various fungi.

The extension of cities, the clearing of forests and the improvement of farms, all result in exterminating various species of birds.

Our attempts to utilize natural resources more thoroughly for our own advantage often disturb balances and bring about epidemics.

In general, the most effective way to fight an epidemic is with a counter-epidemic, that is, a restoring of the biologic balance by encouraging the natural enemies of the pest.

EXPLORATIONS AND PROJECTS

1 To see how man upsets the balance of nature, screen either or both of the United States documentary films entitled *The Plow That Broke the Plains* and *The River.* Relate the scenes shown in the films to conditions in the nearest region in which man's activities are making rapid inroads on natural resources.

2 Report on changes that have taken place in your own community or state, in comparatively recent times, in the prevalence of (*a*) wild life, (*b*) forest land, (*c*) cultivated crops, (*d*) weeds, or (*e*) domestic animals. Account for the reduction in numbers of certain forms and the appearance and spread of new forms. Which changes have produced results favorable to human beings? unfavorable? What species should be further reduced, or what ones should be protected? Be sure you have considered all factors in making your recommendations.

3 To find out what can be done to conserve natural and human resources after balance has been upset, investigate the work of the Tennessee Valley Authority in its program of conservation, flood control and power development.

4 To find out what methods of farming are least wasteful of our nation's soil, investigate some of the better farming practices employed in scientific farming. These methods include general farming, feeding of crops to livestock, careful techniques in the handling of manure, rotation of crops, the use of cover crops, legume crops, green-manure crops, commercial fertilizers, lime, drainage, and methods of tillage which lessen erosion. Report your findings.

5 To investigate the succession of plant forms which take over an area after the climax forest cover has been removed, visit areas that have been cut over re-

cently, a decade ago, and a generation ago. Compare the dominant forms of plant life in each with that found in virgin timberland. Work out the succession of plants which develop in your region when forests are cut or destroyed.

QUESTIONS

1 Why does a plant or animal sometimes thrive better when carried to a strange region?

2 How can insects that are not harmful in one region do great damage in another region?

3 How can insects that are harmless at one time become injurious at another time?

4 What conditions allow one pest or one disease to increase with extreme rapidity at times?

5 What are some of the dangers of interfering with the natural balance of life? What are some of the consequences of man's interference with it?

6 What are the chances that man's fight against insects will someday be finished? Why?

7 What can be done to make possible a larger population without undue crowding?

8 What animals or plants would it be desirable to exterminate from your region? Why?

9 How could the extermination of any plant or animal species bring about undesirable consequences?

10 What is the most effective way to fight any epidemic?

11 What dangers threaten our forest areas?

12 What do you consider the most valuable organic resource of the country? To what extent are we husbanding this resource?

UNIT SEVEN — REVIEW · WHY CANNOT PLANTS AND ANIMALS LIVE FOREVER?

With our own strong desire to live, it is natural for us to seek ways of lengthening individual life, as well as of enriching it. And with the use of modern knowledge we have indeed stretched the average duration of human lives in this country by more than ten years since the early part of the present century. It is likely that we shall succeed in reducing the death-rates at the younger ages still further. But under the most favorable conditions there is still a limit to the length of individual life, and we need not search for physical immortality. Is, then, the life of the individual self-limiting?

The more we study the activities and the processes of plants and animals, the clearer it becomes that it could not be otherwise. Although cells of different tissues or of different species vary greatly in size, each cell reaches a limit of growth. This limit seems necessary because the interchange of materials between the protoplasm and its environment is limited to the ratio of the surface of the cell to the mass.

There is a further limit in the fact that as the individual grows, the parts become more and more specialized. Now living depends upon a close coordination of all the parts. But handicaps or incapacities increase as minor injuries accumulate in specialized structures which cannot regenerate or be repaired. Finally, growing older involves accumulating wastes; lime, silica, and other inert matter are deposited and so reduce the metabolic activities in proportion to the total protoplasm.

A different set of conditions limits both individual and total life. In the whole world there is only so much carbon, only so much phosphorus, only so much nitrogen—a limited amount of each of the elements essential to living protoplasm. These materials are so distributed that only a fraction of the total present is available for living things—in the waters and in the soils near the surface of the earth. And even then they are present in proportions that permit only a fraction of the accessible materials to be used by plants and animals. There is, in fact, a surplus of one or another of these elements almost anywhere, but that does not make up for those that happen to be deficient. Now, if *all* the available materials essential to living things should at any time, and in a particular region, become embodied in living plants and animals, there would be the largest possible amount of protoplasm—and of "life". But then, that condition could last for but a moment; for all the organisms would immediately proceed to starve, or they would begin to destroy one another. In either case, that "maximum" amount of life could not continue.

Living depends upon a continuous flow of materials. Each individual is a center of interchange of materials: this is a basic relationship between an organism and its environment. Some species are related to one another

through their mutual dependence upon this constant stream. Individual plants and animals take from it, but each one also yields to it—at first perhaps only wastes but eventually up to the very last atom of its physical being. The life of a region becomes slowly richer in total life and richer in forms as new species move into it or perhaps evolve in it. These changing inhabitants are capable of operating more efficiently, in the special circumstances, than their predecessors. The total population attains at last an optimum—the climax of plant and animal increase in a balanced system of mutual interdependence.

In the course of slowly building up a climax population, life and death interact. Chlorophyl-bearing plants and some of the simplest species that build up more complex compounds might live indefinitely in the absence of animal species. The animal species, however, could not live in the absence of the former. And by destroying plants and oxidizing organic materials, animals restore to the surroundings raw materials that make possible new plants. There is thus a mutual exchange, a constant give-and-take. Much of this is a quiet, even invisible process—diffusion of gases, diffusion of dissolved substances in water, breathing, absorbing, excreting. But much of it involves activities that are fairly described by the term *struggle*—the capture of prey, the pursuit, the flight, the direct combat. Every phase of this struggle is, of course, destructive of living individuals; but it is also the condition for prolonging the lives—of other individuals.

During this struggle of living beings with one another, as well as with the nonliving environment, the total amount of life may steadily increase—up to the time that a climax is reached. Then the actual amount and the actual composition of the plant and animal population continue to change from moment to moment, from season to season, from year to year; but there is a balance. The life destroyed is quickly replaced by new growths or new births, and the new life destroys its own equivalent.

One feature of life that is at once a source of destruction, and also a means for filling in every possible gap, is the fact that each species not only reproduces, but multiplies. As a result, there is a constant push outward from every single plant, from every group of animals. We might imagine a slower rate of reproduction, a replacement rate, which might permit every individual to live out his own cycle, according to the species. But that would overlook the fact that at each stage every animal species is food for others. The species breeding most slowly could attain an optimum of survivals only as it managed to get food without itself being eaten.

The pressure of population is constantly disturbing the balance in any life-community. When human beings come into a situation that they find favorable, they are disposed to work it intensively. As a result, they often destroy its capacity to maintain human life further. Migration has been part of man's history from the beginning. The conditions of mutual aid, division of labor,

co-operation, have increased the efficiency of human living in any given situation. But they have not necessarily ensured an adjustment of life to the balance of nature, so as to make the conditions continuously suitable for man. It is indeed only in recent times that we have been aware of the underlying balance of the plant and animal forms on which our own existence depends. We can enlarge our population, we can lengthen individual life—but only to a point.

Life has endured for millions of years. But each individual has his little day, and is gone. He gives way to others—to others of many different species or to others of the same species—as he himself has been able to live only as others have given way before him.

UNIT EIGHT

What Are the Uses of Biology?

1 In what ways are biologists any better off than other people?
2 In what kinds of business or profession is biology necessary?
3 How important are the kinds of work that rest on biology?
4 What occupations make use of biological knowledge incidentally or indirectly?
5 What is the use of biology outside of any occupation?
6 How can the ordinary citizen make use of biology?
7 How did people get along before there was any biology?
8 In what ways has biology improved conditions of human life?
9 In what ways has biology made us healthier?
10 In what ways has biology made us happier?

Man shares with other organisms the basic needs—food and air. Air is free, usually, but food one has to get. The helpless human infant survives day by day only because others nourish him and shield him. Gradually, however, the child learns to handle food, eventually to select. And in primitive societies the child also helps gather and prepare food as soon as he can toddle about and discriminate among different leaves, berries, seeds, and so on.

Biology is "learned" in this simple way from the earliest years without lessons, without having a name even. It consists of knowing many plants apart and many animals too: these things you may eat; these you may not eat. Knowing where to find good berries or roots, how to catch fish. Knowing that these things you may eat as you gather them, but these you may eat only after they have been treated—cooked, mashed, ground, cured, mixed with other things.

When thirsty, one drinks water. If the appearance or the taste of the water does not please you, you need not drink it. If you are *very* thirsty, however, you may swallow even unpleasant water. Some peoples cook their water or make teas or some other brews. That was in many cases a good rule, for those who boiled their drinking-water were better off than the others. It was good "biology" even when people did not know the right reason for it.

Compared with those of other mammals, man's activities are most distinctive in his use of tools and in the making of things. Handling things more skillfully and intelligently than other species, he is able to wander over a wider range. He can create shelters out of whatever materials may be at hand—skins of animals, grass, bark, leaves, sticks, stones, snow.

Traditionally men have thought of their material needs as food and shelter—housing and clothing. But even the most primitive peoples need more.

They need tools and weapons, as *means* for getting the primary essentials. And nearly all seem to get satisfaction from gathering odds and ends of things with which they decorate their bodies or their garments and their dwellings. Even weapons and tools are often ornamented.

Ornaments are often symbols of what people deeply treasure. A savage, for example, keeps the tusks or horns of animals he has killed. These are trophies, or proof of his prowess. Some of the North American Indians kept the scalps of enemies they had slain. These things had no trade-in value for food or clothing. They were symbols of worthiness, signs to all the world that this individual amounts to something. They were thus sources of satisfaction and self-assurance. Migrating tribes could not carry with them such trophies. But another feather is no burden, or a notch cut in the handle of the club, or a bead on a string, or another tassel of bright-colored wool. These tokens have value over and above material necessities. They correspond to certain goals that we moderns strive for—titles, medals, ribbons, badges.

Other objectives for which people struggled had religious or magical virtues. Eating the heart of a lion was not only nutritious; it gave one courage. Certain plant and animal parts might cure or prevent sickness, but they had religious or magical virtues in addition. People would go to great pains to get a toad by moonlight or to climb the high mountains for the lucky edelweiss.

It is true that human beings, like other organisms, can continue to live without these ornaments, without these symbolical and magical objects. But as human beings we cannot be happy and comfortable without them. For these objects mean the difference between being nobody and being somebody. They are the outward and visible signs of inner worth. They are necessary for gaining the respect of others, and sometimes for gaining power over them. They are needed to ensure courage and self-confidence and peace of mind. And so they are necessary for health and comfort.

Man reaches out beyond food and clothing and shelter. A better understanding of the forms and activities and characteristics of plants and animals enables people to get more easily what they need. It helps them avoid with greater certainty what may injure or annoy them. Keeping well and avoiding illnesses also depend upon a better knowledge of living things.

We started out by saying that everybody has to know some biology. In all parts of the world people have their local ways of selecting and preparing food, of raising crops, of catching fish or killing game, of preventing pests, of keeping well. They live—well or ill—by what they actually *do*. In addition, however, they have various and conflicting notions to explain how plants and animals work, or reasons for their rules and practices. And these ideas and reasons often conflict with what we today know—or believe.

How does finding out more about living things increase our powers? Or our material resources? Or make us any healthier or happier?

Public health is purchasable; within certain limitations, a community can determine its own death rate.—HERMANN BIGGS, health officer, New York City, 1911

1 What is the best way of keeping well?
2 Why must there be sickness?
3 Can anything in the food or water or air make us sick?
4 Can the lack of anything in the food, water or air make people sick?
5 Can things get into the body in other ways than through the mouth or nose, and make people sick?
6 How can we be sure that the "evil eye" or malicious wishing does not cause disease?
7 Can all diseases be prevented?
8 How can we tell that new ideas about sickness are better than old ones?
9 What disease can be cured by purely mental methods of healing?
10 Why must there be so many specialists?

People have always wondered what made them sick. This is no idle curiosity. The correct answer may solve an important practical problem, namely: How can sickness be cured when it strikes? Men have dared to think even more boldly: How can we prevent sickness from striking?

Early ideas about disease were very much confused. It is easy enough to make guesses about the causes of a particular disorder or of disease in general. But there are always more false guesses than right ones; and in the past there was no way of checking them, to find which was right. How can we tell that the newer ideas and practices about keeping people well are more dependable than earlier ones? Why do doctors change their theories about disease? Why do not doctors always agree about what to do?

How Important Is Sickness?

How We Measure Sickness[1] Ordinarily we become interested in health only when we are in pain or disabled, or when we see others suffering. On an average, six millions of the population of the United States are suffering each day from disabling sickness. Some of us do not lose a day through sickness for years at a stretch. Others are ailing a large part of the time. The average time out from work or from school—or from play—is about ten days a year.

Health-department reports usually deal with communicable diseases only. Another way of measuring the health of populations is to compare their average length of life or their death rates (the number of deaths in one year for

[1]See No. 1, p. 638.

every 1000 of the population). In 1940 the death rate of twenty-seven large American cities with a total population of over twenty-seven million was 11.4. In one city the rate was as low as 8.3, while a rate as high as 15.3 was the worst record. The relative magnitudes of the three rates are shown graphically by these three lines:

11.4 ____

8.3 ___________________________

15.3 ____

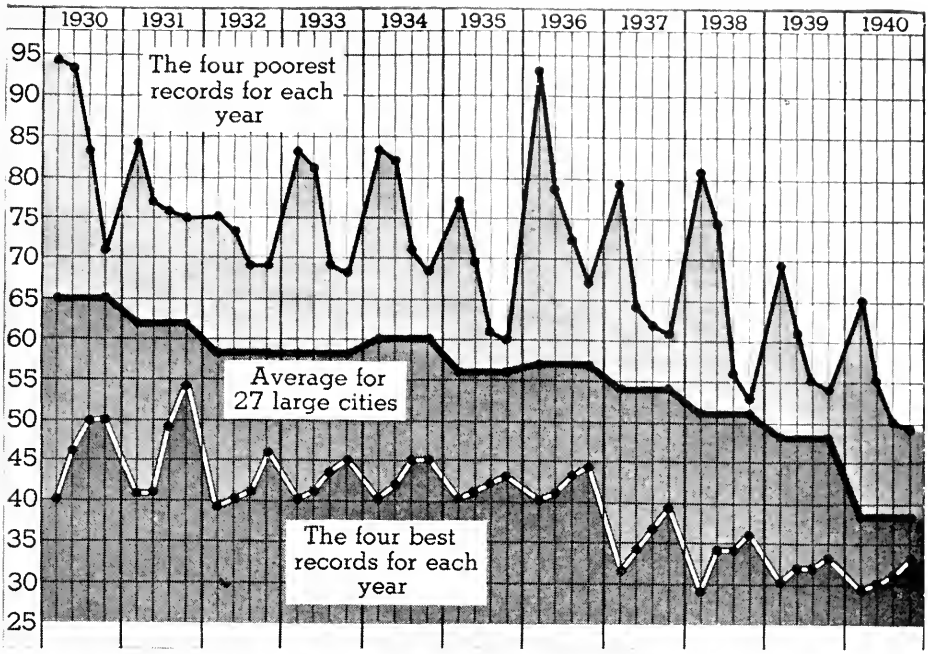
A closer measure of a people's health is the number of babies who die before their first birthday for every thousand born. In the same twenty-seven cities the rate varied from a low of 29 to 30 to a high of over 64; and the rate for the total was 38. Ten years earlier the cities with the best records had an infant death rate of 50.0, while the worst of the records stood at about 90. There has thus been a consistent decline in the infant death rates, but this decline apparently corresponds to improvements in the care and nutrition of children, and in the care of mothers before childbirth.

Aside from these relatively exact measures of illness, we know that there is a tremendous amount of ailing that never gets into the records. Millions keep right on working with such minor troubles as "common colds", sore joints, stiff backs, or just a miserable feeling. And these ailments vary in amount and in frequency not only among the individuals who suffer, but among whole sections or classes of the population.

What Makes These Differences? Among our own acquaintances some are more "healthy" than others, more vigorous, take punishment more easily, spring back, or recover, quickly when struck in any way. Others are easily upset, lose much time ailing, never quite come up to par in anything. Individuals differ in organic vigor and capacity. There are also differences among families. And for that matter, illness strikes unannounced even among people who have excellent health records. Nobody knows who is going to be struck next. But what about differences between one city and another, between one region of the country and another? Why is it that year after year the health record of some cities or counties is consistently better than the average—or consistently worse?

Some of the differences among communities, as to death rates, are due to the composition of the population. In some of the Western states, for example, with a large proportion of adult males and relatively few women and children, the death rate is low. In some communities special health risks are associated with local industries. In general, rural life is considered more wholesome than urban life, although health conditions have been improving more rapidly in cities than in rural areas.

Some of the health differences may be due to the different stocks present



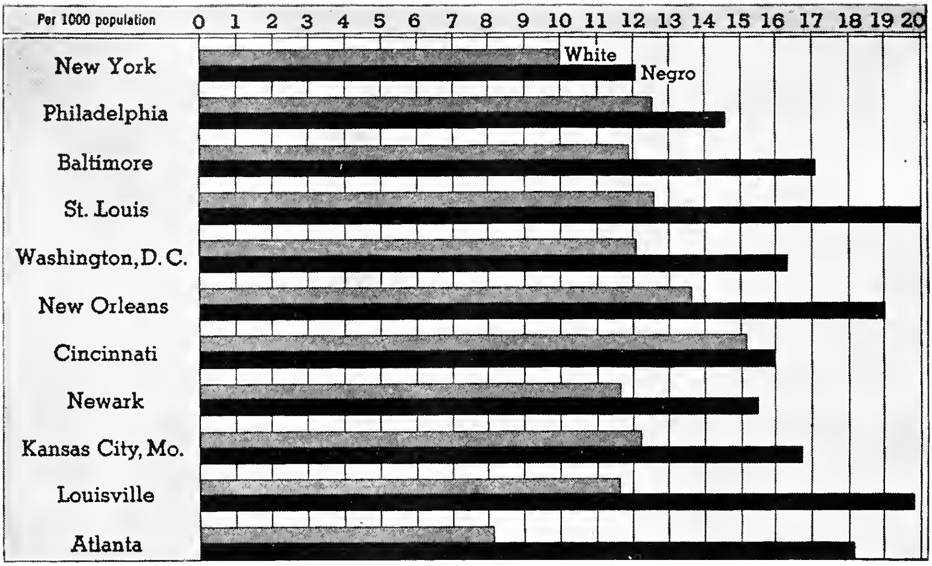
HEALTH DIFFERENCES AMONG CITIES

The infant death rate is steadily declining in all cities, as well as in the country as a whole. When we compare the four cities making the poorest showing in any one year with the four cities making the best showing, we are struck by the large number of deaths that could probably be prevented

in our population. This is, however, not a matter of "race" but of modes of living, of understanding how to meet conditions, how to make adjustments. People who find themselves in a strange region are always at a disadvantage. This is true of explorers and adventurers and of families migrating of necessity or in the hope of improving their lives. Whole populations are pushed around by floods and famines, as well as by wars; and being a stranger in a strange land is always hard and always involves health. Minority and alien groups are generally at a disadvantage and pretty helpless, even in the democratic countries. If we compare the minority races with the white, in various cities, in various parts of the country, we see a preponderance of sickness among the underprivileged.

Minority groups are, in general, more poorly housed, more poorly fed, more poorly clothed. They are likely to be overworked. And they are likely to be underprivileged with respect to schooling and other opportunities to find out better ways of living. They are likely to be anxious and worried.

Poverty and Sickness We can see that economic conditions bear upon health whenever we compare living conditions, on the one hand, with sick-



THE RELATION OF HEALTH TO POSITION IN THE COMMUNITY

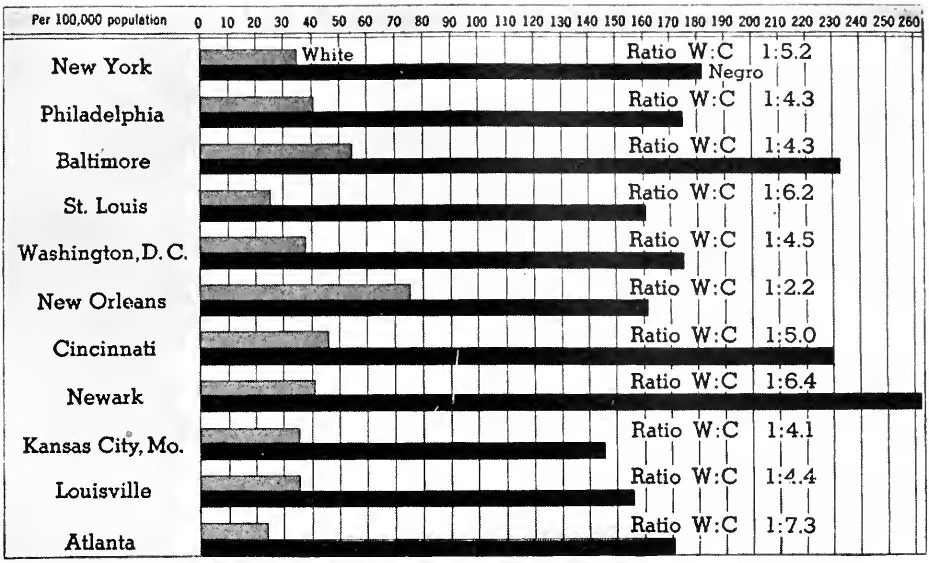
The preponderance of sickness among the underprivileged shows itself in excessive death rates among the colored population. In ten cities having 10 per cent or more of Negro population, the general death rate among colored persons is consistently higher than among white persons

ness rates and death rates on the other. Endless investigations have shown that death rates are considerably higher among the poor than among the comfortable; infant death rates are higher among the poor; tuberculosis illness rates and death rates are higher among the poor; the frequency and severity of illness have been uniformly higher among relief and marginal-income families than among others.

Poverty is associated with sickness because being poor means being unable to get adequate food. It means unsuitable housing—crowded, too cold or too hot, poorly lighted and poorly ventilated, too damp or too dry, lacking in sanitary facilities, and hard to keep clean. Poverty usually means overwork, both at home and on the job. Poverty usually means anxiety, worry, and an excess of irritation.

Sickness and Ignorance Although the poor suffer more from various diseases than the well-to-do, there is among the families of the well-to-do a great deal of preventable illness due to ignorance. Men and women with many years of schooling are not expected to manage an airplane or a poultry farm on the basis of the history they studied; neither can they keep well with their history or languages.

All of us, rich as well as poor, could get better value for what we spend on food, for example, if we knew more. Malnutrition is partly a matter of in-

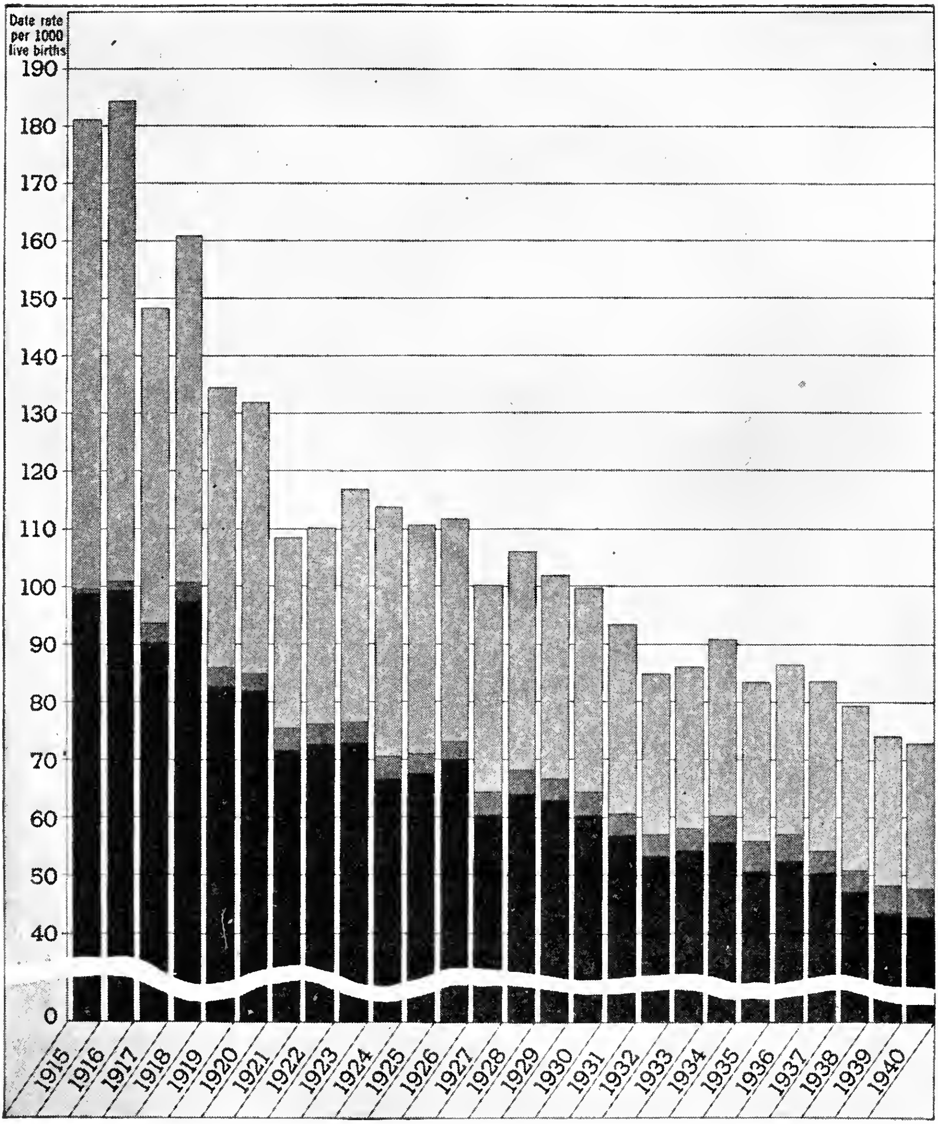


UNEQUAL USE OF SCIENTIFIC KNOWLEDGE IN COMBATING TUBERCULOSIS

Variations in the death rates from preventable diseases are related to position in the community. The death rate from tuberculosis among colored populations, for example, is from two to seven times as great as among the whites in eleven large cities that have more than 10 per cent of Negroes in their populations

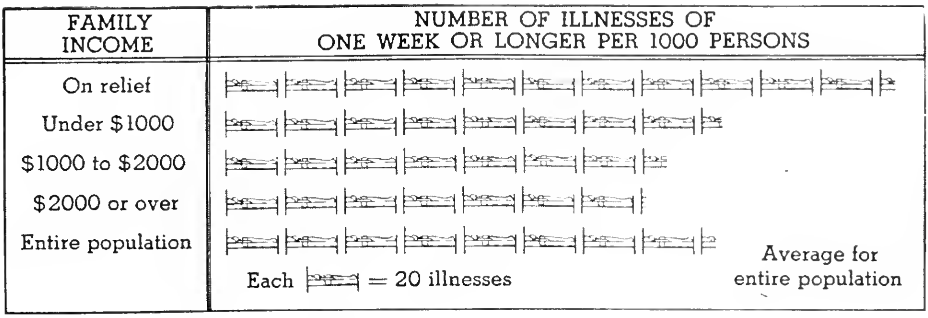
sufficient food, but it is also a matter of faulty choice of food. Wise choice calls for knowledge and understanding, which do not necessarily come with money. It is probably significant that the states which have been spending most to improve their schools have consistently had good health records, whereas those which have been spending least for schools have the highest death rates. "Health" and "education" and "wealth" are not independent facts. Poor people, for example, who suffer most from sickness, are also deprived of their share in modern knowledge and understanding.

It is true that for the individual and for the family it is practically impossible to make use of new scientific knowledge as it comes along. But a community that is well informed will get its officials or its professional leaders to produce results that seem miraculous to those who do not understand what is happening. Over a period of years before the Second World War the health department of Detroit carried on a special campaign to locate every case of tuberculosis and to provide the necessary care and treatment. When the war came, with its great strain upon workers, its exceptional crowding, and its deterioration of living conditions, the health administration continued its efforts to drive the tuberculosis rate down and was successful, whereas in other war-industry centers the rate turned upward.



INFANT SURVIVAL AND SOCIAL STATUS IN THE UNITED STATES

The infant death rates shown in solid black are for white babies. Averages for entire population are shown by tops of gray bands, from about 100 in 1915 to less than 50 in 1940. The highest rates are for nonwhites. We might interpret the differences as organic or inherited differences but for the fact that, as social and economic conditions improved, the infant death rates went down more rapidly for the nonwhites than for the whites

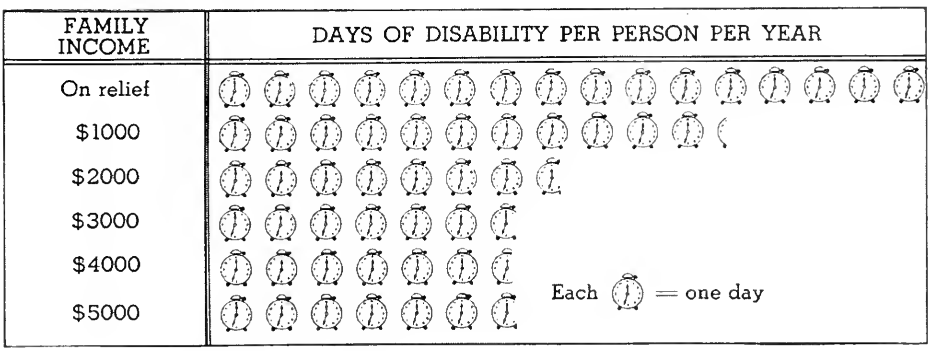


THE POOR GET SICK MORE OFTEN

It has always been known that being poor increases the chances of being sick. But how poor must people be to be sicker than the average? Does a high enough income insure against all illness? And are not people sometimes poor because they are too sick to produce and earn?

Ways of Living[1] If we compare peoples in different periods or in different parts of the world, we find certain connections between modes of life and states of health or well-being. Epidemic diseases are, of course, associated with crowding. Famine is associated with depending too closely upon "nature"—living from hand to mouth, making no provision for possible drought or for other interferences with crops or game. We are no better able than the ancients to control the weather, but we do know a little farther in advance when changes in weather are likely to take place, and we can plan farther ahead.

Within our large and mixed population, families and groups differ greatly in their ways of managing their homes and persons, in their ways of eating and dressing, in their ways of working, resting, playing. These variations bring



THE POOR REMAIN SICK LONGER

Not only is sickness more frequent among the poor, but the average loss of time for each illness is also greater among them. If it were merely a matter of luck whether sickness strikes one person rather than another, there should not be this great difference in time needed to recover

[1]See No. 2, p. 638.

about differences in health or sickness. Some parts of our population keep well because they manage according to our best knowledge and make use of expert knowledge and skills when there is need. Others are kept well by being looked after by competent persons—as inmates of certain institutions. But other parts of the population just drift along, and these consistently furnish an excessive share of the ailing and the sick and the premature deaths.

How Do Other Organisms Influence Our Health?

Invaders[1] The germ theory of disease, with which we commonly associate the name of Louis Pasteur (see page 444), is really several hundred years old. During the Middle Ages most physicians and scientists suspected that plagues were due to "germs" carried from sick persons. But it was impossible to prove the existence of these objects, because they are so small. The very name *malaria* reveals the common understanding of the sources or causes of disease. Everybody knew that it was the "bad air"—especially bad night air—that brought on the fever and ague. People continued to speak of what passed between one person and another as "vapors" or "miasmas"—and to think of them as "spirits".

Pasteur, who was not a physician, but a chemist, had discovered minute objects as always present in the fermentation of wine and milk, and present in sick silkworms. But he had not succeeded in proving beyond doubt that a particular species of microbe was an essential factor in a particular disease.

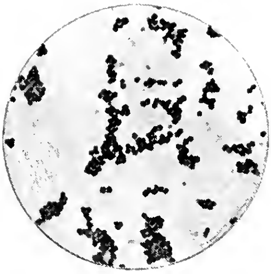
The first actual proof, or test, of Pasteur's germ theory was made by a German physician, Robert Koch (1843–1910), working with an epidemic disease of cattle—spleen fever, or anthrax. This proof consists of three distinct steps:

1. Finding the specific bacteria or other suspected parasites *always present* in every organism showing the symptoms of the disease;
2. Isolating and multiplying the specific parasite in a pure growth *outside the body* of the host, usually in a sterilized preparation of special food;
3. Inducing the *same disease* in a healthy organism by inoculating it with material from the pure culture.

Bacteria of one kind or another will grow wherever there is organic matter, moisture, and a temperature not too low or too high. They are destroyed by sunshine, by various chemicals, by X rays, and by the temperature of boiling water. Many species endure prolonged boiling. The metabolism of bacteria will be suspended when the temperature gets too low, but as a rule microbes cannot be destroyed by freezing.

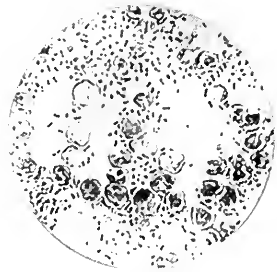
Some diseases are caused by plant parasites more complex than bacteria. The skin disease known as ringworm is due to a moldlike fungus (see page 375) and has nothing to do with worms. The irritation and damage are annoying

[1]See No. 3, p. 638.



Staphylococci

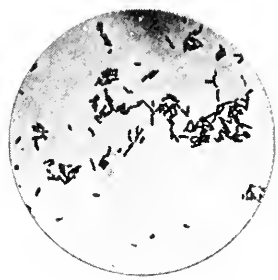
Streptococci



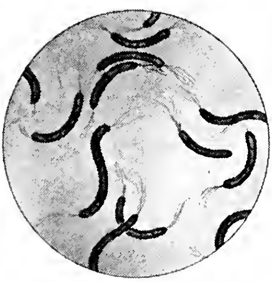
Pneumococci

Typhoid bacilli

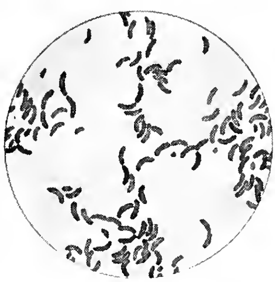
Anthrax bacilli



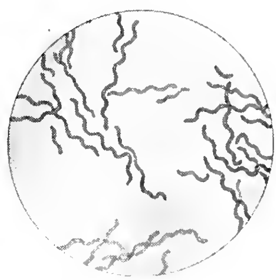
Glanders bacilli



Spirillum undula
(*Showing flagella*)



Cholera spirilla



Spirillum rubrum

United States Army Medical Museum

TYPES OF BACTERIA

Bacteria are divided into three main groups according to the general shape of the cell: round-cell, or coccus, type, in which the cells cling together either in chains or in clumps; rod-shape, or bacillus, type; and spiral, or spirillum, type. Some bacilli and some spirilla move by means of cilia. Each group includes pathogenic, or disease-producing, bacteria

and unpleasant, but not serious. Treatment should be left to a physician, and persons who are infected should use care to prevent the spread of the parasite. The condition known as "athlete's foot" is also due to a fungal parasite. The treatment and prevention of the disease, and of others not caused by bacteria, are possible because of knowledge derived from studies started by the germ theory.

Virus Disease By saving from rabies a little boy who had been bitten by a mad dog, Pasteur convinced the world of the soundness of his germ theory of disease (see page 444). This brilliant achievement aroused tremendous public interest and led to the establishment of the Pasteur Institute in Paris, and later of similar institutes for research into the problem of disease, in all parts of the world. But to this day nobody has yet seen the germ of rabies, or hydrophobia.

We have seen that in rabies, smallpox, and several other diseases the specific cause of the disorder is a filterable virus (see pages 444–445). A virus is more like a protein than like an organism, although it multiplies like a parasite at the expense of the host. Virus diseases destroy plants, as well as animals; and they arouse in the host reactions similar to those produced by injurious bacteria. Infection by virus is also similar to that by bacteria. For these reasons virus diseases are treated very much like bacterial diseases.

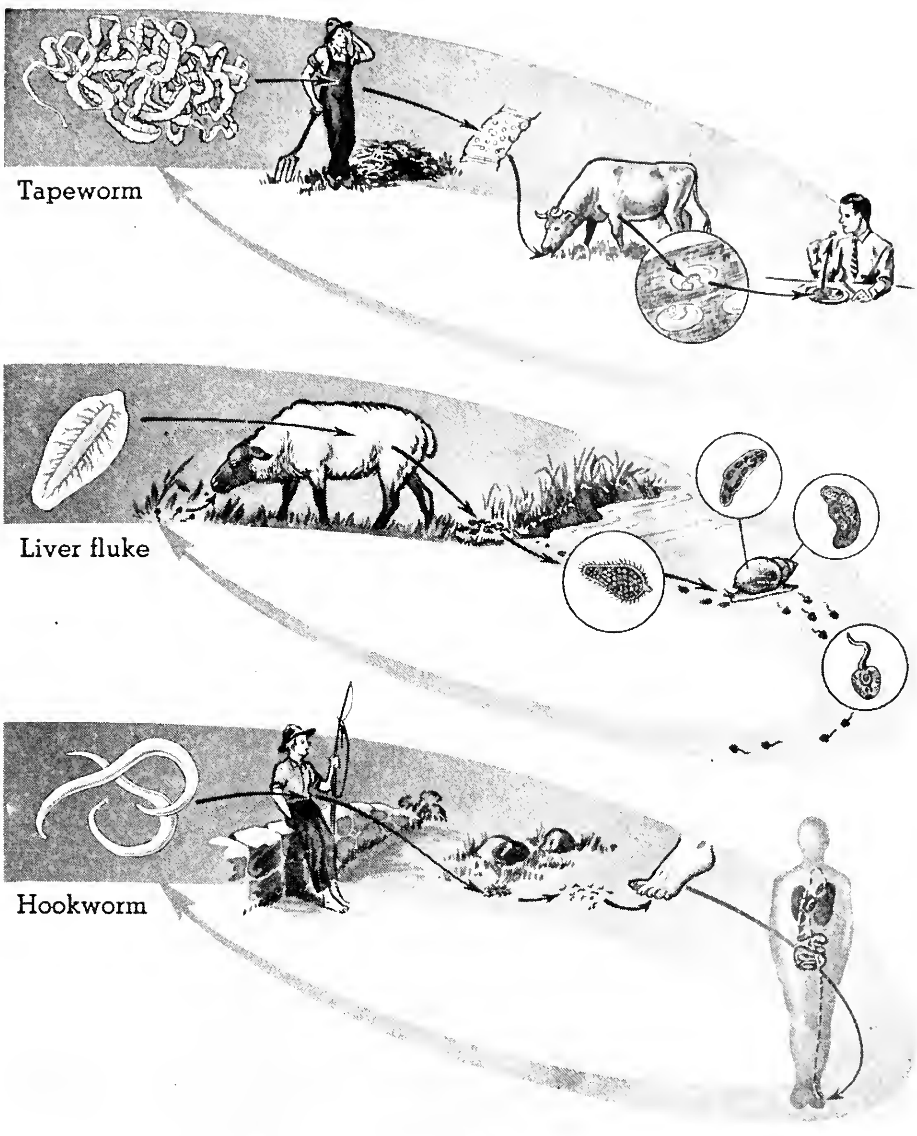
Animal Microbes Many protozoa are parasitic. Malaria, dysentery, syphilis, African sleeping-sickness, tick-fever in cattle, and other diseases in man and the lower animals are caused by different species of protozoa.

Many species of flatworms and roundworms live as parasites in the bodies of higher animals. They are important to us because they injure either human beings or domestic animals.

A very striking fact in the life history of some of these animals is that distinct stages in the life cycle are passed in different hosts (see illustration opposite). The same fact has been observed in many parasitic plants, as the wheat rust, one variety of which spends part of the cycle on the wheat and part on the barberry plant (see page 594).

This fact of multiple hosts led to a great deal of confusion when scientists first attempted to make a complete study of these parasite species. In the end it turned out to be of great help in our struggle to overcome them, since the more links there are in a chain, the better are our chances of finding one that we can break.

Parasite Worms The name tapeworm is applied to several species of flatworms of the genus Taenia (see illustration opposite). It has a comparatively simple structure, consisting of hardly more than a series of flat sacs containing excretory tubes and reproductive organs, with a holdfast, or anchoring organ, at the end (or rather the beginning) of the series. Three or four species of tapeworms inhabit the human intestine.



ALTERNATE HOSTS OF PARASITIC WORMS

The complex life history of the parasitic liver fluke was the first one understood to include alternation of hosts and of distinct generations. Tapeworm is transmitted to the human host by infested meat that has not been cooked enough to kill the worms in the resting stage. Hookworm can be prevented by suitable sanitation, wearing shoes and avoiding contact with the soil

The secondary stage of the tapeworm is sometimes injurious to the other host also, forming what is called a *bladder-worm*. Sometimes the human organism serves as the secondary host. In that case the bladder-worm may cause serious destruction of some tissue or organ.

Parasites of the roundworm group embed themselves in the muscles of a mammal. One of these, *Trichinella*, usually alternates between man and pig, producing trichinosis in human beings, and the condition known as "measly pork" in the meat industry.

Tapeworm, trichinella and hundreds of other parasitic species find their sustenance and their way of life in the food eaten by mammals and other larger animals—the food and its migrations through the bodies of these animals. We can control many of these parasites (1) by individual or family care in the selecting and cooking of meat, and (2) by public regulation and inspection of the raising of food animals and the preparation and marketing of meat products.

The Hookworm Early in this century investigations conducted under the direction of Dr. Charles W. Stiles (1867–1941), of the United States Public Health Service, disclosed the fact that the "poor whites" of our Southern states were suffering from an intestinal parasite, the hookworm. This roundworm depleted their energies, emotional and intellectual, as well as physical (see illustration, p. 615). The announcement of this discovery was at first ridiculed; nobody would take the "laziness germ" seriously. Self-righteous people said, "Laziness is laziness, and that's all there is to it," or they said, "There's no use blaming sickness or worms for being lazy." Yet the fact remains that with the removal of the parasite these white folks appear to be equal to the best stocks in the country.

In some districts almost every inhabitant was infected when the investigations were made. The remedy and the prevention are comparatively simple. The parasite can be driven from the host by the use of thymol and epsom salts. Where sanitary privies and modern toilets are installed, the parasites are unable to multiply in the surface soil and come under complete control. But in the South, where nearly a third of our population lives and where intestinal parasites are most prevalent, 15 per cent of the farm homes had no toilet facilities of any kind in 1940.

Ticks and Mites The itch often causes extreme irritation, but its chief danger is the great temptation to scratch, for that may lead to infection by some more dangerous parasite. The little animal that causes the itch is a *mite*, a nearly invisible relative of the spiders. Preventing the itch is largely a matter of personal cleanliness. Another skin parasite related to spiders is the *tick*, which is about an eighth of an inch long. This bloodsucker may produce a painful bite, but its greatest danger is as a possible carrier of disease germs (see illustration opposite).

Bureau of Entomology and Plant Quarantine, U.S.D.A.

THE TICK

The tick is known to transmit Rocky Mountain fever, or spotted fever, among human beings. Another species transmits the Texas cattle-fever, which was formerly a very expensive scourge in this country. (The ovipositor, on the abdomen, points forward behind the mouth, so that the discharged eggs spread all around the female's head)

How Do People Become Infected?

Communicable Diseases Following the methods and the principles developed by Koch, investigators have identified the specific parasites causing some of the most important human diseases, such as tuberculosis, diphtheria, syphilis, typhoid fever, tetanus, pneumonia, malaria, gonorrhea, Asiatic cholera, bubonic plague and hookworm. These diseases are important because they have again and again killed from a tenth to nearly half the population in great plagues or epidemics. And without flaring up into plagues they have been the greatest causes of deaths, year in and year out, in many regions.

Common observation and countless experiments with plants and animals leave us certain that the communicable diseases are caused by parasites or viruses. And that they are communicated by the entrance of something material into the body—either through one of the regular openings to the interior, as the mouth, nose, or urethra, or else through a cut or break in the skin.

Wounds and Germs For ages common experience had recognized the general fact that wounds fester. Nobody knew why; nor why some festering, or pus-making, ended in healing, whereas other festering was fatal. That is the way wounds act. Whether the skin is broken by a gunshot, a jagged rock, or a surgeon's knife, the two possibilities are present. In hospitals it had been observed that however skillful a surgeon might be, his patients often died as a result of the festering, or "blood-poisoning" as it was called. There was also an excessive number of maternal deaths associated with fever and blood-poisoning. And nobody knew why, nor what to do about it.

In Boston, Oliver Wendell Holmes (the father of the late Supreme Court Justice Holmes) had suspected from his hospital experience that this *septicemia*, or "rotting of blood", was due to *something* brought into the patient through breaks in tissues. In Vienna and in other cities observant physicians and surgeons had come to the same conclusion. After Pasteur and Koch had made their demonstrations, an English surgeon, working in Edinburgh, Joseph Lister (1827–1912), hit upon the idea of keeping "germs" out of wounds. He fitted his surgery up with suspended sheets that he soaked with carbolic acid. He cleaned the wounds of his patients with this germ-killing solution. And he promptly reduced the casualties following surgical operations.

Since then many *anti*-septics have been used for destroying bacteria in wounds of all kinds, and especially in surgery. The problem has always been to find something powerful enough to kill all the kinds of germs, but not likely to injure the host or the tissues. With the rapid development of synthetic chemistry, the "sulfa" drugs have come in recent years to be widely used with most amazing results (see page 242). They have been especially valuable on the battlefield and in surgical situations complicated by festering. Many persons suffering from inflammation of the appendix come to the surgeon after the appendix has burst. Then millions of bacteria of several kinds are thrown into the body cavity, spreading the inflammation to the tender tissues, frequently with fatal results. It has been found that pouring dry sulfanilamide powder on the affected area soon destroys the germs and gives the patient a chance to recover. Several hospitals have reported series of from two to three hundred such cases without a death.

The Chain of Infection[1] It is not difficult to analyze the problem of protecting a population against communicable diseases. In addition to whatever physicians and nurses can do for the patient attacked by a parasite, it is necessary merely to attack the enemy at one of three points: (1) where parasites leave the host; (2) where parasites travel to another host; (3) where parasites enter a new host.

In actual practice, however, the task is not so simple. We need first to know, in the case of each disease, something of the nature of the parasite or virus. Then we have to know in exact detail just at what points and in what manner it gets out of the patient, and just how it is carried from one host to the next, and just how it enters the body. We cannot count upon complete isolation either to render the present patient harmless or all possible victims secure.

The problem is complicated still further by the fact that several serious diseases are transmitted by common insects. The common housefly, for example, was found to be the chief *vector*, or conveyor, of typhoid-fever germs, and later also of other intestinal parasites. A commission on the causes of epidemic

[1]See Nos. 4 and 5, p. 639.

fevers in the army camps during the Spanish-American War reported that "flies swarmed over infected fecal matter in the pits and fed upon the food prepared for the soldiers in the mess tents. In some instances where lime had recently been sprinkled over the contents of the pits, flies with their feet whitened with lime were seen walking over the food." We can readily understand why it was that more soldiers were killed by intestinal diseases than by Spanish bullets.

The fly lays her eggs in manure, or in decaying meat or fish or other garbage. She visits also exposed food of all kinds, open wounds on animals, and the excrements of man and other animals. This insect is thus in an excellent position to collect and distribute a varied assortment of bacteria.

The many species of mosquitoes, which together cover nearly the whole of the habitable earth, have probably always been a nuisance. But now we know that several species are also the sole carriers of various serious diseases, especially malaria and yellow-fever. Moreover, the mosquito is an intermediate host of the parasite involved, and not merely a mechanical conveyor, like the fly.

Fleas appear to be links in a chain that involves man and one of the most dreaded of diseases, the bubonic plague. The specific bacillus that causes this disease was discovered in 1894, but the mode of infection remained unknown until after the First World War. The Chinese had long ago noticed that there was some connection between the dying of rats in large numbers and the appearance of the plague. Now scientists know that the disease in men and the plague in rats is caused by the same bacillus, that indeed the parasite is primarily one that lives in the rat. But it is transmitted from rat to rat by fleas, which sometimes get away from dead rats and infect men and women. Here, then, the flea is a simple vector, but rats and other rodents act as breeding centers, or reservoirs, of the parasites.

How Are Disease-Carriers Exterminated?

Fighting the Housefly As the horse is gradually removed from our daily lives, opportunities for flies to breed and multiply are reduced. There are still too many about, however, and they are still a menace to health. The individual family cannot protect itself so long as flies are free to breed in neighbors' yards, free to fly through the air, and free to alight on food.

Whether through a public-health agency or through the intelligent cooperation of all citizens, the fly has to be treated as a community problem. It is necessary to screen or cover all garbage and manure, all stables, and all body discharges that are not immediately removed by suitable sewers or sanitary privies. It is necessary to screen or cover all food, whether for private use or for sale. Every purchaser of food can help the community, as well as

The Strategy of Combating Communicable Diseases

Control of

Exit	**Transit**	**Entry**
Destroy parasites or virus in discharges—sputum of tuberculous, stools of typhoid and hookworm	Keep dust out of circulation—dried sputum, spray from sneezing, coughing, speaking	Avoid contact with persons in infectious state of any disease
Burn clothes and utensils, surgical dressings	Protect supplies of water, food, milk	Avoid breathing air containing dust, sprays from other persons
Sterilize pus and fluids chemically	Keep possible carriers out of mouth—things handled, fingers	Cover face when necessary—surgeons and nurses
Disinfect clothing, premises	Individualize towels, washcloths, handkerchiefs, toothbrushes, hairbrushes, napkins	Guard cleanliness of eating and drinking utensils, hands, dishes, towels, etc.
Screen privies	Sterilize media between people—utensils in public eating and drinking places, swimming pools, gymnasium floors	Avoid bites of animals, stings of insects, etc., scratching skin
Control sewage and other wastes	Guard against personal contacts that may convey infection	Disinfect cuts, bruises, wounds
Avoid spitting		Avoid contact of bare feet on possibly infected floors, the ground, etc.
Cover sneezing, coughing		Prepare and serve food to avoid transfer of infection (trichinosis)

Destruction of

Insects and Other Animals That May Act as Vectors of Disease Germs

himself, by avoiding dealers whose premises harbor filth and the flies it breeds or attracts. And we can all help by keeping our own premises clean and free from flies.

Mosquitoes and Malaria Of all the diseases from which man has suffered, malaria is said to be the most widespread. It occurs all around the earth and as far north and as far south of the equator as mosquitoes breed. Wherever malaria is present, it shortens life, it keeps people from their work, it reduces human capacity to work and to enjoy life, it demands costly drugs, nursing, and medical services, and it throws millions of fertile acres out of use.

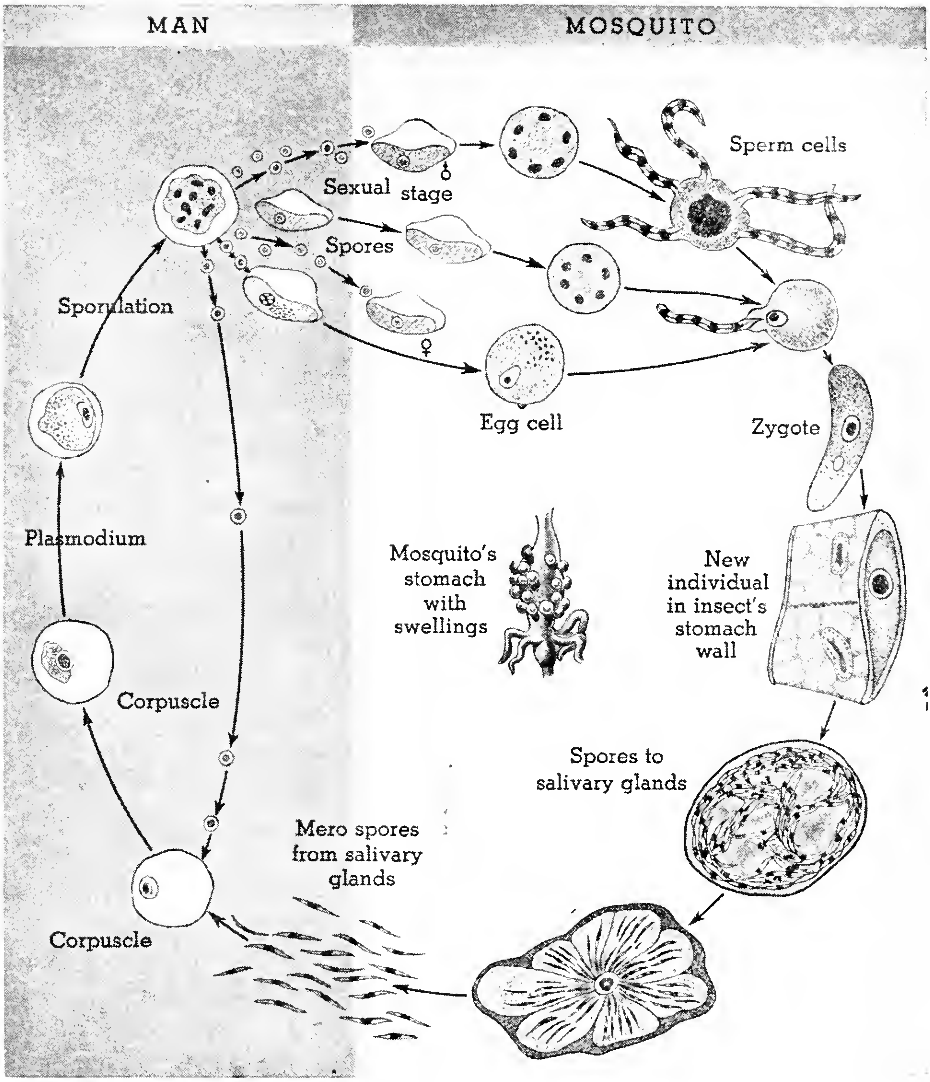
In India malaria kills over a million human beings a year, besides causing untold misery to millions of others. A French scientist, Alphonse Laveran (1845–1922), working in Algeria, was able to infect volunteers with the blood of malaria patients, but he could not find out how infection takes place naturally. The disease is caused by any one of three or four species of protozoa related to the ameba and known as the *plasmodium* of malaria. The animal feeds upon the red corpuscles of the blood of its host and then *sporulates*, that is, breaks up into a large number of tiny bits of protoplasm called spores. The spores enter new corpuscles, and the process is repeated indefinitely, greatly weakening the victim and sometimes killing him (see illustration, p. 622).

In 1900 scientists in England and Italy co-operated in an elaborate experiment to find the connection between malaria and mosquitoes. A number of volunteers lived in the badly malarious Roman Campagna through the most dangerous part of the year, from early in July until late in October. But they lived in houses that were carefully screened against mosquitoes, and when they went out in the evening (when *Anopheles* is about), they always wore veils and gloves. *Not one became sick, although many of their neighbors became infected with malaria during the summer.*

At the same time, some mosquitoes were caught and allowed to suck blood from malaria patients. These mosquitoes were shipped to England in little cages, and stung two young men who had never suffered from the disease and who lived in a region where there had been no cases of malaria. In the course of a few days *both developed the characteristic symptoms of the disease.*

This experiment showed that (1) the night air and the vapors from the swamps of the Campagna are harmless and (2) the sting of a mosquito that had once bitten a malaria patient is dangerous. Mosquitoes raised from the eggs and allowed to bite a person do not transmit the disease. Nor does drinking water in which the mosquitoes develop. Today nobody who knows the *facts* can have any doubt as to the relation between the mosquito and the transmission of malaria (see illustration, p. 623).

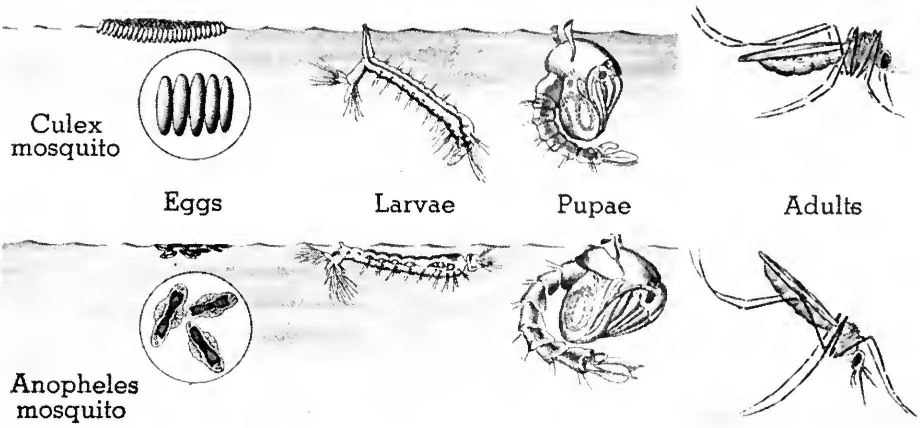
Mosquitoes and Yellow Fever In the past yellow fever has been much more fatal than malaria. It occurs only in tropical or semitropical regions, although there have been epidemics of yellow fever as far north as Philadel-



THE MALARIA PARASITE

Inside the body of the mosquito the parasite undergoes many changes, which include the formation of sexual stages and a conjugation. The zygotes find their way into the walls of the stomach; and after repeated subdivision of the protoplasm, tiny spores in swellings formed in the salivary glands are discharged when the insect stings again

phia, New York, and Boston. It had long been suspected by many students of the problem that this disease is transmitted by mosquitoes. At the close of the Spanish-American War a commission of American physicians definitely proved the charge against *Stegomyia fasciata*, now called *Aëdes*. The com-



KINDS OF MOSQUITOES

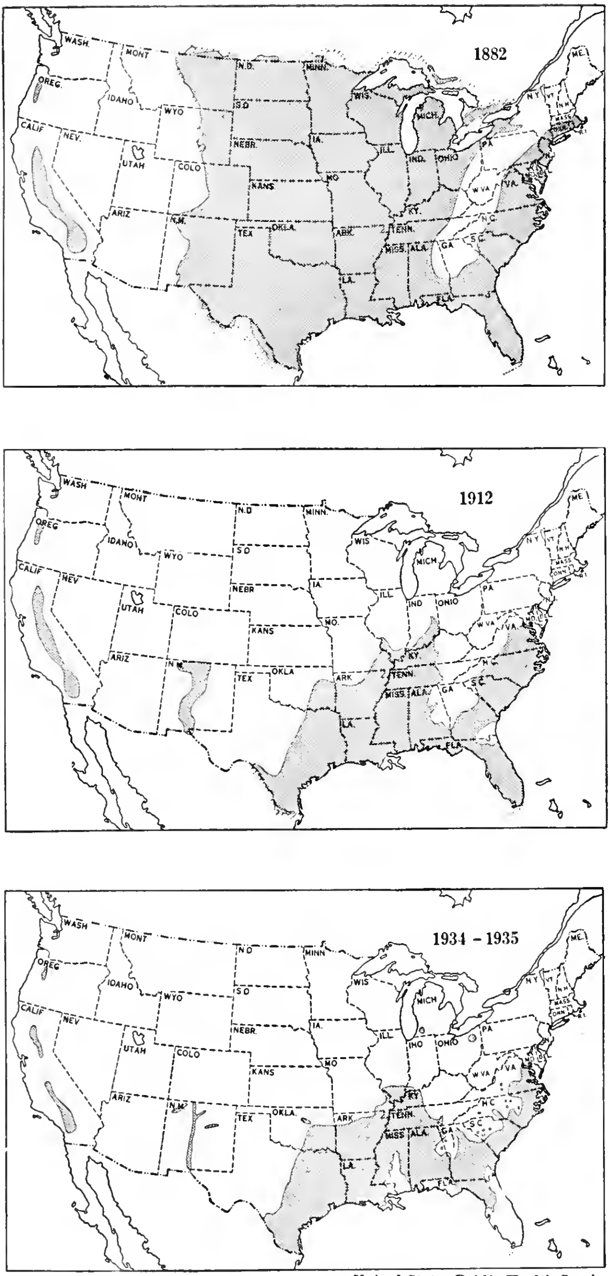
The most common mosquito in this country is the Culex, which does not transmit malaria. Malaria is transmitted only by the Anopheles. The two genera are quite distinct at every stage in the life history

mission consisted of Dr. Walter Reed, Dr. James Carroll, and Dr. Jesse W. Lazear. They were assisted by a Cuban, Aristide Agramonte, who had recovered from the disease and was therefore immune.

Two well-screened cottages were used. In one of the two cottages the ventilation was intentionally very poor. In the other, having very good ventilation, a mosquito-tight screen separated the two halves. In the first cottage three volunteers received clothing and bedding from men who were suffering from yellow fever or who had died with the disease. Not one became infected.

In the other building eleven volunteers on one side of the screen allowed themselves to be stung by mosquitoes that had drawn blood from yellow-fever patients two weeks earlier: in four days they all came down with the disease. Volunteers on the other side of the screen—breathing "the same air" and living in much the same way, but not stung by mosquitoes—remained well. In the course of the experiments Dr. Carroll and Dr. Lazear were also stung and became sick, the latter dying as a result. It has since been found that yellow fever is caused by a virus.

The mosquito lays her eggs in quiet water. Here the larva and pupa grow and develop. The best means of preventing malaria and yellow fever are therefore (1) ditches to drain off marshy land, (2) cartloads of dirt to fill in low-lying spots, (3) oil on such puddles as cannot be filled or drained, and (4) lids or screens to cover cisterns, tanks or buckets in which water must be kept standing. In addition, it is necessary to make sure that there are no old



United States Public Health Service

DECLINE OF MALARIAL AREAS

The systematic elimination of breeding places has removed the mosquito from many areas, and at the same time malaria has declined, in some cases to absolute zero

cans and other possible containers for water where the female mosquito can reach them. Without such breeding-places one year would see the end of all mosquitoes in all co-operative communities. In larger bodies of water where there are fish, these will usually destroy the larvae. In the shallow margins, however, where the fish cannot reach them, the mosquitoes have things their own way. It is necessary to keep the borders of ponds clear of weeds, sedges, etc.

The practical effect of exterminating the mosquito is shown by the decrease of malaria and yellow fever (see maps). For decades French engineers had made repeated attempts to construct the Panama Canal. Each time the "fever" made it impossible to continue the work. When the United States took over the enterprise, the first step was to establish sanitary conditions. And the largest part of the problem was to exterminate mosquitoes by eliminating their breeding-places.

When the Second World War moved into the tropics, it suddenly raised serious health problems for the armies of countries that had considered themselves quite finished with malaria and yellow fever and other tropical diseases. When the Japanese captured the Dutch East Indies, the supply of quinin was cut off from the United Nations. It was out of the question to drain swamps and fill in marshes in the Philippines: Corregidor and Bataan submitted to malaria quite as much as to the bombs and machine guns of the enemy. Since then, however, chemists and physiologists have developed a substitute for quinin, starting with a German product, "atrabine", which we are able to make in our own laboratories. Atrabine is not as effective as quinin in curing malaria, but has been helpful as a preventive, especially when combined with quinin. In the meantime a very satisfactory vaccine to meet the yellow-fever menace has been developed through researches of scientists supported by the Rockefeller Foundation.

Rats, Plagues and Fleas The plague has spread from the Orient, and at various times cases have appeared at several ports in the United States. In dealing with this danger, efforts are directed toward killing rats and fleas rather than toward killing bacteria. A ship coming from an affected port is thoroughly fumigated to kill the fleas and rats (see illustration, p. 628). A search is made for hiding-places in which rats may be concealed. In California the ground-squirrels had become infected with the plague bacillus early in this century. Systematic patrols had to be established to catch rats and ground-squirrels, which are regularly examined for possible infection. To protect human life it is necessary either to exterminate some of our neighbors or to see that they keep well. We can hardly undertake to protect the rats and other rodents from plague; we can protect ourselves only by exterminating the rats.

Lice and Ticks Trench fever is seldom fatal, but it caused a great deal of suffering and incapacity among soldiers during the First World War. Volunteers from the ambulance and field-hospital units allowed themselves to be infected with the blood of patients. Other volunteers, who allowed themselves to be bitten by lice taken from the bodies of patients, developed the disease. Still others, however, living under exactly the same conditions, but bitten by lice from healthy men, remained unaffected. These experiments showed that the infection is carried by the louse. By "delousing" all the men, including officers, the disease was brought under control.

In the past there were frequent epidemics of typhus and of related diseases among crowded people or where it was difficult to keep clean. In these epidemics the mortality was often very high—from 20 to nearly 50 per cent. All these diseases are now known to be caused by similar microbes, which are parasitic upon rats and other small mammals, as well as upon man. And they are transmitted by insects—chiefly the body louse.

Several diseases resemble typhus in their outward symptoms. The group

includes ship-fever, jail-fever, camp-fever and Rocky Mountain spotted fever. The Rocky Mountain fever is transmitted by a tick (see page 616). Since the flea is comparatively rare in the United States, ship-fever, jail-fever and camp-fever have not become epidemic here.

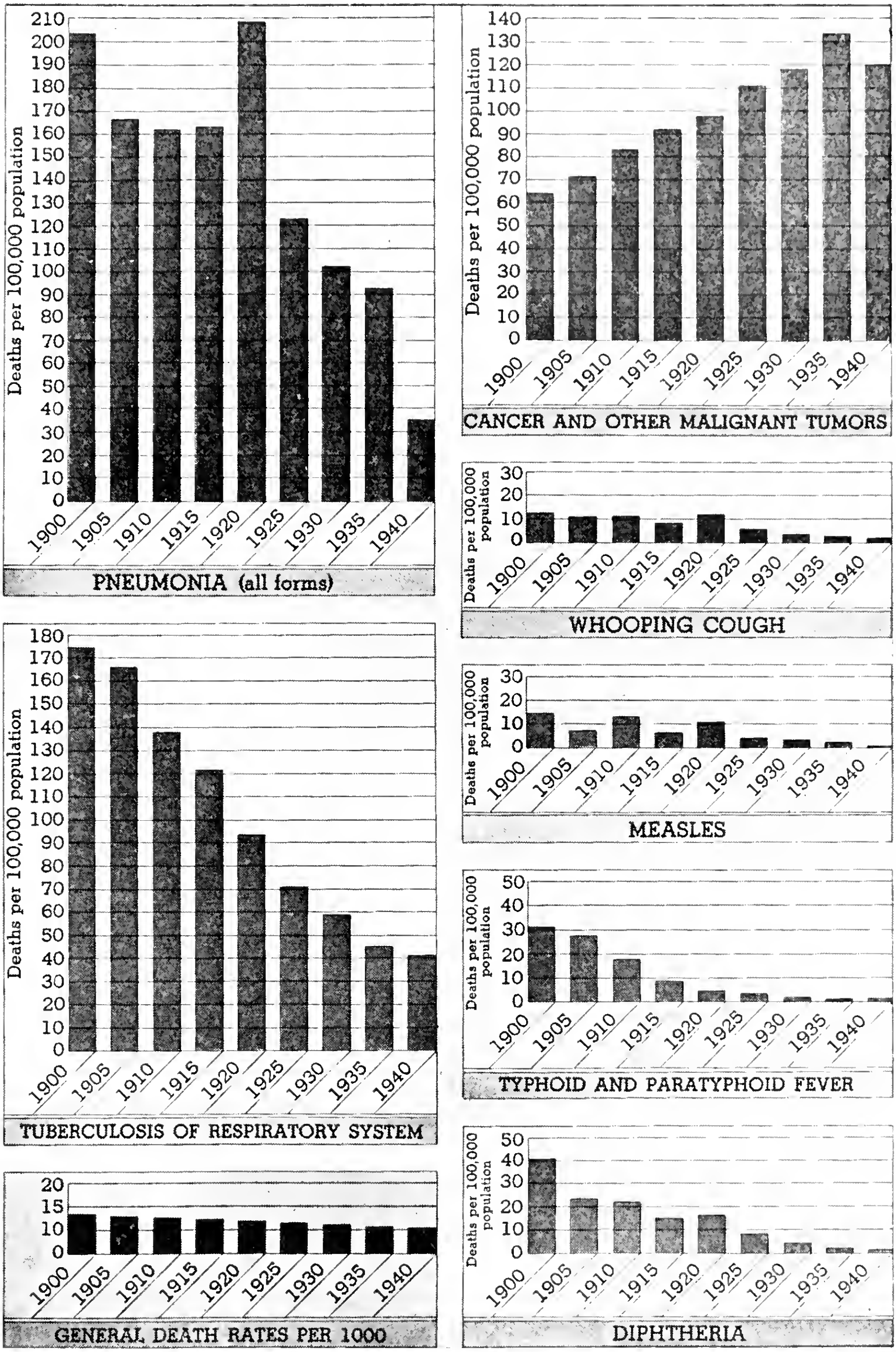
Are All Diseases Caused by Parasites?

The Fight against Specific Diseases We have succeeded remarkably well in *preventing* communicable diseases. We have not exterminated all specific or communicable diseases, of course, and probably never shall. But we have completely exterminated some of them in some areas (see illustration opposite).

In the early part of the century, rates for various communicable diseases fluctuated irregularly. Later there was a steady decline in the incidence of many of these diseases, and especially in the mortality which they caused. In the chart on the opposite page, the figures on the left of each graph indicate the number of deaths per year in the case of each disease, for 100,000 persons. For the general death rate, however, the figures are per thousand of population.

It is always a particular person who is well—or sick. Yet most individuals, whether as patients or as potential victims of infection, have done very little to reduce or eliminate communicable diseases. We go about our affairs protected by experts and specialists of whose existence most of us do not even know. Increasingly, however, each of us must co-operate if the optimum results are to be attained. We notify health officers of the existence of communicable diseases. We remain at home when we suspect an infectious disease. We avoid acts that may endanger others, such as spitting, disposing carelessly of refuse, smoke, vapors, dust, and so on. We have to accept inspection of our premises or persons, vaccination and other immunizations, and quarantine regulations. We do many things that we would not do spontaneously or would not do willingly if left to ourselves. We avoid doing what we should otherwise want to do. To get the benefits of science we have to accept numerous regulations, restraints of our "personal liberties".

Nonspecific Diseases The revolutionary results of the germ theory made it reasonable to suspect parasites in every disease. We have learned, however, that the metabolism may be disturbed by a variety of "causes" other than infections. Specific deficiencies—or excesses—in diet may modify growth or development, and so result in distinct diseases. Simple goiter, for example, has been traced to a shortage of iodine. A faulty balance of calcium and phosphorus seems to influence unfavorably the development of bones and teeth. An excess of selenium in the soil brings about a sick condition in cattle, and probably in human beings too by way of the plants they eat. Pellagra,



DECLINE OF COMMUNICABLE DISEASES

United States Public Health Service

KEEPING RATS FROM GETTING ASHORE — OR ABOARD

Ships plying between ports in which there are infected rats and other ports receive special attention from health officers. Metal shields are used to prevent rats infected with the plague from getting off the boats, or from getting aboard in plague areas. In addition, of course, pains are taken to destroy rats on ships, and to prevent their breeding

scurvy, beriberi, rickets, and other diseases are due to the lack of specific vitamins in the diet.

Modern industry and modern city living have brought into our environment physical and chemical changes that often disturb us. Various dusts and fumes affect the breathing organs, or introduce into the body substances that modify the metabolism. The materials handled by workers affect the skin, the nerve-endings, and perhaps deeper tissues and organs. Lighting conditions, unusual or loud sounds, affect the inner co-ordination of processes, even when we are not aware of them. Eyestrain has been found to result in nervous tension which in turn influences the digestive process and possibly other processes by way of the autonomic nervous system and the endocrines.

General fatigue has long been recognized to be an outcome of excessive exer-

tions and anxieties. Indeed, many of the so-called "functional" disorders, in which the physicians can find no structural or chemical defects in any organs, appear to result from strains and anxieties arising out of working and living conditions, rather than from physical or chemical features of the environment. Certain forms of "heart disease" appear to come from disturbed emotional states rather than from chemical or physical injuries of the organ.

The rising rate of certain noninfectious diseases may be in part explained by the lengthening of the average span of life. That is, as the proportion of older men and women in the population becomes greater, the disorders peculiar to old age will naturally increase. The greatest gains from preventing disease have come in the lower age-groups. Each child starts out today with a very much better chance of getting past his tenth, twentieth, or fortieth birthday because he is not so likely to succumb to diphtheria, smallpox, typhoid or malaria. But his chances are so much greater of eventually incurring deteriorations of the kidneys, the nervous system, the heart or the arteries.

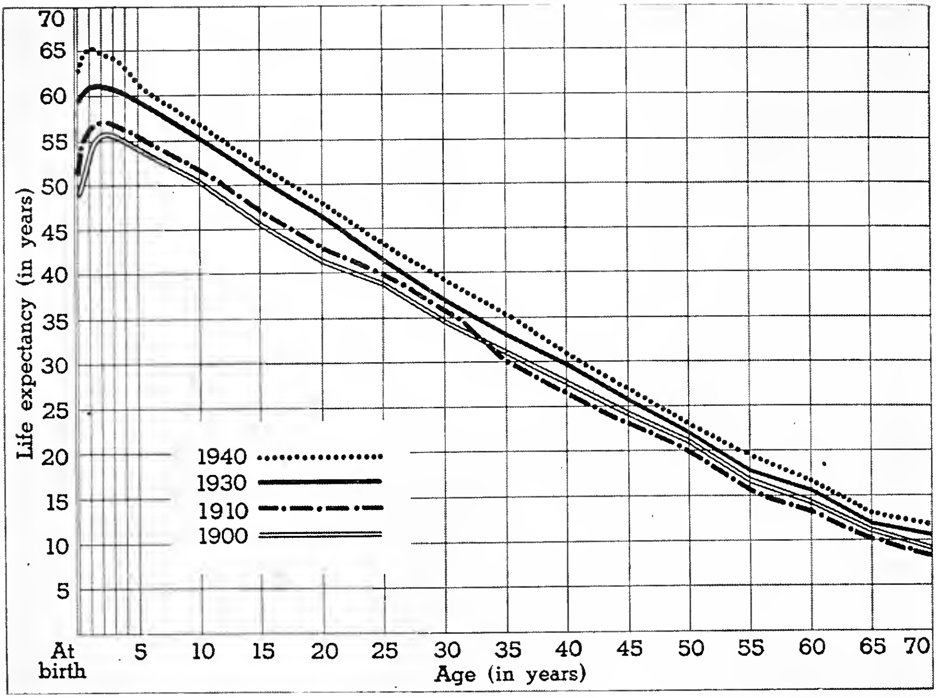
We cannot blame the parasites for all our troubles. Many of our diseases result from our faulty management of our daily lives. There have been great improvements in general health as a result of better diet, better housing, better working and living conditions, better use of our resources for enjoying life. We could prevent much illness, however, if we used our present knowledge more generally. And there is still a great deal to find out.

How Can People Get the Benefit of Scientific Knowledge about Keeping Well?

Joint Services[1] People moving from village to city, or from one region to another, have always had to learn new ways of living. But today the individual is helpless among the many specialists with their various knowledges and skills. He must learn both to depend upon others instead of trying to do everything *by* himself, and to serve others instead of trying to do everything *for* himself. To protect the individual and to ensure him what he must have, it became necessary for neighbors to co-operate in ever larger groups. Eventually, co-operation extends to the whole civilized world, particularly where health is involved.

A community health program starts out to be protective and preventive. More and more, however, it comes to include positive services. In a sparse community, for example, it may be necessary to regulate the location and treatment of cesspools and the disposal of refuse, in order to prevent the contamination of wells or of the soil. But in cities it becomes necessary to establish joint water supplies and elaborate systems for the disposal of household wastes, garbage, and so on. At one stage of development it is enough if public

[1]See Nos. 6 and 7, p. 639.

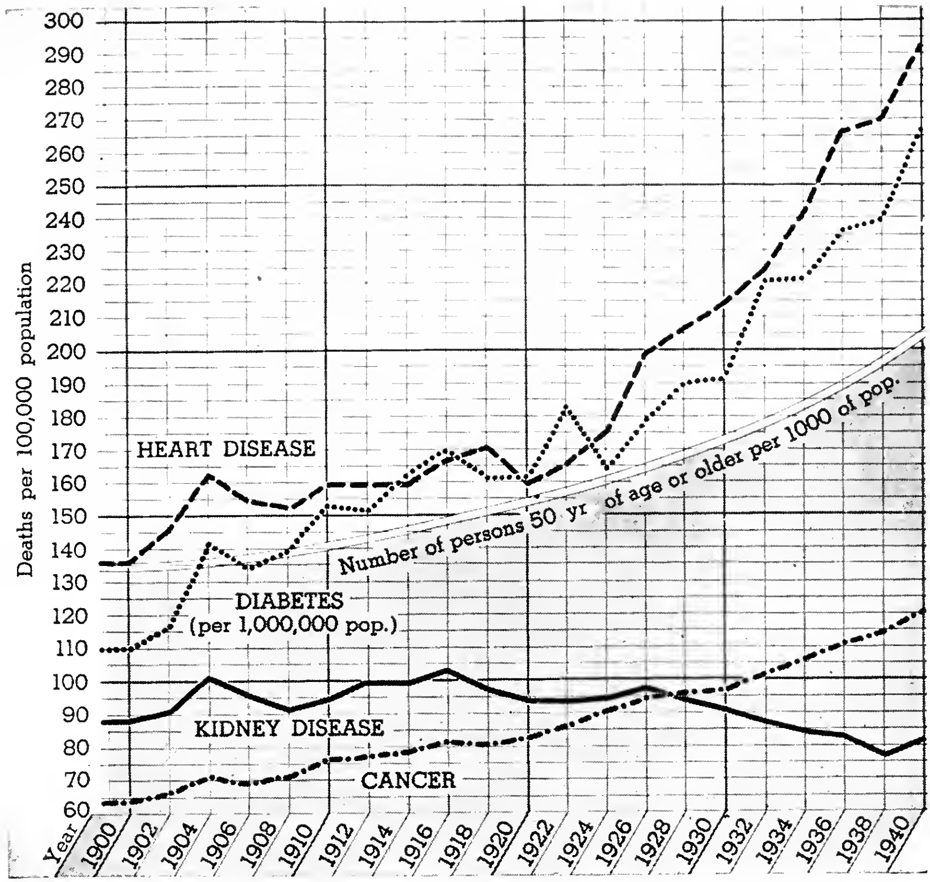


THE LENGTHENING SPAN OF LIFE

Each child born in a civilized community today starts out with a much better chance of getting past his tenth, twentieth or fortieth year than had his parents or grandparents and their contemporaries. He is not so likely to succumb to diphtheria, smallpox, typhoid, malaria, scarlet fever, or other communicable disease. He has an even chance of attaining seventy years

officials inform physicians and private citizens about improved or standard tests, serums, and other special materials and procedures for curing or preventing disease. Later it is found to be more effective and more economical to supply materials, tests, immunizations, inspections, and other services directly through a central agency.

Water Supply and Sewage Disposal As population becomes more dense, surface wells become less adequate, and they are in increasing danger of pollution. Deep wells are, as a rule, quite satisfactory for small towns, but cannot supply large cities. Cities usually depend upon lakes, streams and reservoirs that collect the runoff from a vast watershed. The entire watershed, as well as the reservoir, must be protected against pollution by excreta and industrial wastes. Suspended matter and harmful germs are removed by means of storage, chemical treatment, settling basins, filtration, or some combination of these methods, depending upon the circumstances. Bacteria in the water are destroyed by very small amounts of chlorine.



INCREASE IN ORGANIC DISEASES

As communicable diseases come under control, more men and women survive to advanced ages. More deaths, therefore, result from various diseases of old age—cancer, heart disease, kidney disease and others

The privy and the home-sewage-disposal plant found on individual farms or in outlying portions of towns frequently become dangers to health. The cesspool lets the raw sewage drain quickly into the ground water, where it sometimes pollutes wells and springs in the vicinity. The septic tank is much safer than the cesspool, for in it any harmful microbes are destroyed by anaerobic bacteria.

In towns and cities elaborate sewer systems are installed to remove wastes from the individual homes. Some cities allow the sewage to flow into a stream or lake without any treatment. This is cheap, but it makes the stream unfit for bathing and swimming and fishing; and it may create a distinct nuisance. Furthermore, the bacteria which live on the decaying refuse may use so much

of the oxygen dissolved in the stream that fish and other desirable forms of life can no longer survive. Such disposal of sewage may endanger the health of cities located downstream.

To avoid these disadvantages sewage is managed by several different methods. These include sand filters and chemical treatment for precipitating suspended matter. Other satisfactory systems depend upon the action of aerobic or anaerobic organisms.

As population becomes more concentrated, it is found to be more satisfactory from the point of view of health to have central municipal agencies remove and dispose of ashes, rubbish and garbage. And in the long run community agencies are the most economical.

Food Protection A large part of our food comes to us in sealed packages. We do not know where or of what the food is made. Expanding commerce brings us food products from foreign lands. As individuals, we cannot tell from the appearances or the taste whether the preparations contain harmful preservatives or coloring matter or adulterants, or whether they lack any of the essentials. It has become necessary to protect buyers of food and other products through public regulations and official agencies.

As we learn more about the relation of food to health and efficiency, and as we become more and more separated from the sources of supply, the public must protect the buyer still further. We must be assured (1) that what is offered is *suitable* for our purposes and (2) that it is *harmless*.

Because food travels greater distances from its source, and is kept for longer periods, nearly all the states regulate the sale of prepared meats, fruits, vegetables, fish, that may become spoiled or contaminated. Shipping spoiled food from one state to another is prohibited by federal laws. In many cities special ordinances authorize officials to seize and destroy any unsuitable food that they may find, and to penalize dealers or manufacturers who offer such food for sale.

It has been practically impossible to obtain milk in large quantities without excessive numbers of bacteria. The practice of *pasteurization* has therefore come into general use. This consists of keeping the milk at a temperature of 145° F for twenty minutes.

Food in Wartime In Great Britain during the first three years of the Second World War, the general health of the population appeared to improve. And this in spite of the great strains brought on by the bombings and other conditions, and in spite of the rationing of food. The improvement is in part explained by the fact that a considerable fraction of the food used was raised on the island instead of being imported. This made certain that only needed food was produced, while imports were carefully planned. And the rationing ensured everybody a suitable diet within the limits of what was available.

In every factory employing two hundred and fifty or more workers, com-

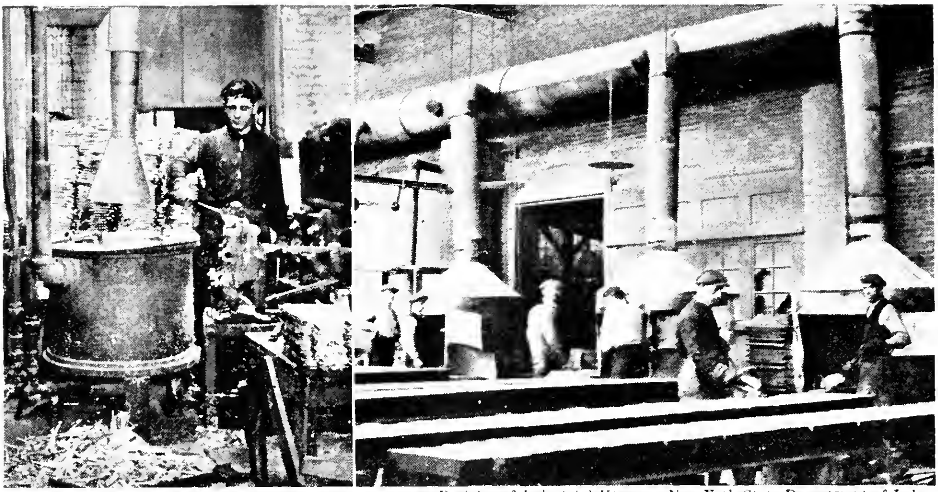
munal meals were served. That meant better marketing, better preparing and cooking, and a more economical use of food. At all schools lunches were served; that made certain at least one substantial meal of good quality for every school child. Younger children and mothers received relatively richer meals, with prior rights to limited supplies of milk. Similar methods were developed in the United States, in Canada, and in other countries, demonstrating the value of applying scientific methods to our common but complex problems.

Government and Microbes A bare list of the governmental agencies and activities related to health will give us an idea of how far we depend upon our environment and upon one another. Many diseases are subjected to quarantine and placarding. Public laboratories provide vaccines, serums, and other special preparations, and supervise the manufacture and sale of such products for profit. Official laboratories examine specimens of blood and of other fluids or tissues obtained from patients for diagnosis. We inspect dwellings, schools, factories, camps, theaters, and other places where people live or assemble, to make sure that conditions are sanitary. We exclude sick people from schools, and if we knew how we would exclude them also from places of work and of amusement. We disinfect discharges from the bodies of sick people and disinfect premises that have become infected. We inspect slaughterhouses and regulate the cleaning of vessels in public eating places. We regulate drinking-cups in public places and the wrapping of bread before it leaves the bakery.

In some cities, visiting nurses, ambulance service and public hospitals help to keep down the amount of sickness and to reduce the suffering. States license physicians, dentists, druggists, nurses and midwives, as well as barbers, manicurists and masseurs, to maintain suitable standards of health; and they license plumbers, electricians and automobile drivers to ensure greater safety.

Prohibitions and Regulations Conditions that made it necessary for the public to regulate its water and food supplies made it necessary to regulate the sale of drugs also. All people are interested in their health, but most people are ignorant in regard to the conditions of health. The vast drug industry has made available to millions of people convenient packages of standard remedies, chemicals and household supplies related to health and cleanliness. But this business has also frightened and deceived the public into buying remedies for "symptoms" which we might better disregard or else bring to the attention of reliable physicians. Men and women have been induced to drug themselves with worthless and even harmful "remedies" while neglecting their actual needs.

Gradually the public is coming to realize that it has a right to know what it is buying and what merits there may be in the strange products. Moreover, it is coming to feel strongly that people's health is more important than any



Division of Industrial Hygiene, New York State Department of Labor

Bad Conditions Good Conditions

RELATION OF WORKING CONDITIONS TO HEALTH

Wherever lead dusts or fumes are produced, effective exhausts and perfect cleanliness are necessary to prevent lead poisoning. As industrial managers spend more effort and more money trying to prevent injuries and accidents among workers, as they improve conditions for the health of workers and their families, they save more and more in the cost of production. It is actually cheaper to keep workers well than to pretend that health is a purely private matter

private business. Some states prohibit absolutely the sale of dangerous drugs except on the prescription of a licensed physician. In general, we are becoming suspicious of any business that thrives on "secrets" or on the ignorance of other people.

Working Conditions The men and women whose work makes living conditions better for all of us are themselves often exposed to bad working conditions. Some occupations are strikingly dangerous, involving serious accidents. Among these are marine service, quarrying and mining, iron and steel manufacture, and work under high air pressure. Other occupations are dangerous to health, although they are not classified as hazardous or as involving great risk of accident. The dangers in such occupations arise from the special materials used or from the conditions under which the work is carried on. In the making of chinaware and pottery, for example, there may be danger of lead poisoning.

In some manufacturing establishments, dangers may lie in badly ventilated workrooms. As soon as we recognize that *the objectionable conditions are not necessary*, we must take steps to find remedies. And as science has helped to improve conditions of living and to increase production, it can be made to improve conditions of working. Air-conditioning, for example, is being more

and more widely installed for reasons of comfort and health. Yet the art was first developed because variations in moisture and temperature sometimes interfered with speed or quality of production in textile mills and in printing.

In many industries it is impossible to prevent the formation of dirt of various kinds, which may be injurious to the physical health of the workers. In some industries the processes themselves call for a higher or a lower temperature than is best for human beings. In many industries poisonous gases and fumes are produced. Most acid fumes may "eat away" the delicate linings of the lungs. Alcohol fumes and the fumes of other solvents used in varnishes, phosphorus fumes, lead fumes, and other fumes are absorbed and so poison the body.

In certain occupations the worker is constantly exposed to injurious dust. (1) Coal dust and the fluff from the fibers used in spinning and weaving may crust or cover part of the lung lining. This reduces actual breathing surfaces and lowers the resistance of the cells to disease microbes. (2) Hard, sharp particles of metal or stone and fine sand, or silica, may scratch the delicate linings of the air sacs and expose them to the entrance of disease microbes. Such dust is produced where metals or stones are ground, polished or chipped, and where sandblasts are used. (3) Street and house dusts may carry disease germs of various kinds.

Intelligent managers long ago discovered that it was profitable from a strictly business point of view to maintain working conditions that protected the health of the workers and that made the surroundings pleasant and agreeable. Most workers, however, were neither fortunate enough to select intelligent managers nor able, otherwise, to insist upon suitable conditions. They were obliged, therefore, either to organize like other professional or business groups and to use their joint influence to better the situation, or else to wait patiently until the community was sufficiently sensitive and sufficiently responsible to regulate working conditions through public agencies.

In the course of years we have gradually developed public standards, and set up machinery for enforcing standards in industrial and commercial establishments. These standards cover a wide range, ensuring a subsistence wage, sanitary washrooms, suitable drinking-water, suitable places for meals, and the removal of dusts, fumes and gases from the atmosphere. They include also prevention of disturbing noises, provision of safety appliances, regulation of hours of work, and prohibition of certain kinds of work to women and children.

We know enough biology to raise the physical and mental well-being of the entire population to a much higher level than that which the top quarter now enjoys. We know also that from an economic point of view good health pays; that is, it brings returns beyond anything that it may cost in money. But we do not yet know how to organize our practical affairs so as to make full use of our science for all the people.

Some Occupational Hazards

Kinds of Injury	Sources	Industries Affected
DUSTS		
Scratching or piercing lung epithelium	Silica Glass	Mining, rock drilling, stonecutting, foundry work, brickmaking, grinding, glassmaking, glassworking and grinding
	Steel	Machinery operations, steelworking and grinding
Crusting or covering lung lining: interference with breathing; reduction of resistance to invading germs or viruses	Asbestos dust Talc	Insulation work, roofing, painting, packing, flooring
	Wood	Milling, furniture-making, fixtures, luggage, autos, sporting goods, cabinets, caskets, or milling, woodworking of all kinds
	Plant fiber Paper Rubber	Textile industries
Conveying infective agents	Grain Leather Feather Fur	
METALS		
Certain metals that are volatile are absorbed and produce various organic disturbances or poisoning	Lead	Pottery and earthenware, printing, soldering, storage battery
	Zinc	Mining, smelter, galvanizing, fabricating
	Chromium Silver	Plating, working
	Copper Mercury	Mining, refining, working
FUMES AND VAPORS		
Poison in various ways	Carbon monoxide	Foundries, hat industry, use of gas-heated appliances
	Carbon tetrachloride	Solvent in many industries, cleaning works
	Acetone Benzol Paints Lacquers	Spray painting
RADIUM		
Superficial and more serious "burns"	Radium emanations	Laboratory workers, hospital aids, luminous-dial manufacture

Kinds of Injury	Sources	Industries Affected
SKIN IRRITANTS		
Dry or chafe the skin in various ways; producing sores or tender areas; sometimes specific or systematic reactions. Expose to infections; affect blood vessels; affect nerves or nerve endings	Dyes Solvents Oils Paint-removers Chlorinated compounds Degreasing materials	Dye works Chemical works Electrical works Rubber works Textile industry Fur industry Airplane industry
PHYSICAL STRAINS		
Back injuries Hernia Foot injuries Varicose veins	Lifting or carrying excessive weights Standing too long on feet; walking excessively or in awkward positions	Various industries, construction work, transportation Store work, patrolling
EXPLOSIONS AND OTHER ACCIDENTS		
Physical injuries to various parts of body from blows, being thrown violently; from burns, cuts, electric shocks, etc.	Explosions of boilers or engines Static electricity igniting mixtures of air and organic dusts or vapors Moving parts of machinery, spars, propellers, etc. Falling objects, rock, dirt Fire hazard	Marine work, transportation Flour mills, aniline works, gasoline industries Heavy industries, construction work, mining Power plants

In Brief

With every improvement in economic conditions, there is a consistent lowering of sickness and mortality rates. Among underprivileged groups both sickness rates and death rates are relatively high.

To make use of new knowledge and to fit into changing conditions, individuals and members of families need constantly to re-educate themselves and to change their practices.

The spread of communicable diseases can be prevented by attacking the parasites at the point where they leave the host, in the course of transit to a second host, or at points of entry into the body.

By exterminating flies and mosquitoes, it has been possible to reduce radically or even to eliminate typhoid fever, malaria, yellow fever, and other diseases.

Rat fleas, body lice and wood ticks are known carriers of serious diseases; we can fight these diseases most effectively by fighting the carriers and rats or other secondary hosts.

As the average span of life is lengthened by improved nutrition and the prevention of communicable diseases, there is an increase of "old age" diseases, resulting from deterioration of tissues or organs. Studies of these conditions point to better ways of managing our lives.

There is a limit to the use of scientific knowledge by the individual or by the family; co-operation with others is increasingly necessary both to prevent the spread of communicable diseases and to ensure adequate water supplies, disposal of sewage and wastes, and other essential services.

Increasingly we depend upon joint supervision, regulation, and direct services by public agencies to protect and promote the health of the community and of its members.

Our actual health conditions, because of fixed habits, customs, and ideas or "beliefs", lag behind those that scientific knowledge might make possible.

EXPLORATIONS AND PROJECTS

1 To find out the chief causes of ill health, investigate mortality and morbidity tables from the departments of health of your city or state, from the United States Public Health Service, and from the statistical reports of various insurance companies. Information can be obtained on the number of cases of infectious diseases and on the chief causes of death at different age levels. Supplement these data with a study of the severity, nature and control of each of the more frequent causes of ill health or death.

2 To find how medical care is provided, read and discuss various publications of the United States Public Health Service and of the American Medical Association, and also various Public Affairs Pamphlets. Organize material and arrange to discuss how the public can best assure itself of needed health and medical services.

3 To determine the relative number of bacteria in various waters, collect in sterilized bottles samples of water from near-by lakes, streams, swimming pools, wells, cisterns, and city-supply taps. Bring samples to the laboratory immediately and place in a refrigerator. Dilute 1 cc of each sample in 99 cc of sterile water. Shake each dilution thoroughly; then pour 1 cc of the dilution into a sterile Petri dish and add sterile liquid nutrient agar.[1] It is well to make duplicate cultures of each sample. Allow cultures to harden and then place upside down in a warm part of the room. Examine in 48 hours. By counting the colonies, determine the number of bacteria present in each sample of water.

[1]To prepare desiccated nutrient agar for use, dissolve 25 g of the powder in 1 l of boiling water. Place some of the nutrient agar in each Petri dish and sterilize the Petri dishes by keeping them in a steam bath for 30 min or in a pressure cooker at 15-pounds pressure for 20 min.

4 To find out whether water is contaminated with sewage bacteria, inoculate fermentation-tubes of brilliant green-bile medium[1] with 1 cc of each of several samples of water. Try samples from wells, springs, swimming pools, rivers and the like. Incubate the cultures at 37.5° C. Examine in 24 hours to see whether fermentation has produced gas in any of the cultures. The presence of gas indicates the presence of *Bacillus coli*.[2] Summarize results to show which of the waters are and which are not safe to drink, or to swim in.

5 To determine the relative number of bacteria present in various places, expose sterile agar plates and find out how many bacteria grow from each inoculation. Expose dishes to the air in the classroom, in the street, in the home; test clean silverware and dishes; expose plates to doorknobs, drinking fountains, pencils, coins, fingers (both before and after careful washing with soap). Inoculate other plates by kissing, by sneezing, with scrapings from under the fingernails, with combs, with used handkerchiefs, with dishwater, with footprints of a housefly, etc. Incubate cultures and examine after 24 hours. Tabulate and summarize your results, to tell in what kinds of places bacteria are abundant. Relate your findings to the spread of disease.

6 To study the sanitation of your community, take trips to the water-purification plant, the incinerator, and the sewage-disposal plant. Find out how each operates. If such plants are not accessible for study, investigate the water supply of various homes or farms, as well as methods used in disposing of refuse and sewage. Report your findings.

7 To find out about the work of your local health department, arrange to visit its bureaus or divisions of statistics, foods and drugs, and preventable diseases; the laboratories, and various clinics, especially those dealing with child health, tuberculosis and venereal diseases. Plan a panel discussion in which you share your findings.

QUESTIONS

1 In what ways can we prevent the spread of communicable diseases?

2 Why are not doctors and nurses, who are so much in contact with sick people, more often sick than others?

3 What is the advantage of having physicians report certain diseases to the state or city health officer? What is the disadvantage?

4 How can one preserve his own health without depending upon others?

[1]Brilliant green-bile medium can be purchased in dry form from laboratory supply houses. This medium contains three ingredients which differentiate *Bacillus coli* from other forms of bacteria, namely, aniline dye, which is poisonous to other bacteria, but not to *B. coli* in the dilution used; bile, which kills most bacteria, but which does not inhibit the growth of *B. coli*; and lactose sugar, which is fermented readily by *B. coli* but not by most other bacteria. The formation of gas in this medium within a period of 24 hours is quite conclusive evidence of the presence of *B. coli*. If gas does not form within 24 hours, but does form to a limited extent later, the test is considered negative, as soil bacteria of a certain group also grow to a limited extent in this medium.

[2]*Bacillus coli* normally grows within the intestines of warm-blooded animals. The presence of *B. coli* in a sample of water indicates contamination with fecal matter, which may or may not be human excreta. If human excreta are draining into the water, there is, of course, danger that intestinal parasites which cause typhoid fever may also be present.

5 How does travel to new regions bring dangers to health?

6 What is there to show that flies are dangerous neighbors?

7 What can the individual do for his protection if the community continues to tolerate flies?

8 What is the evidence that mosquitoes endanger health?

9 At what point in the life history of the mosquito is it most easily exterminated?

10 How can mankind use knowledge of the life histories and habits of other species?

11 What is the connection between a people's habits and customs and its likelihood of becoming infested with hookworm? with trichina?

12 How can the home water supply be protected in the country?

13 How can house waste, garbage, and other refuse be kept from injuring health?

14 What methods of milk inspection are used in your community? of dairy inspection? of testing milk as to quality? of testing milk as to bacteria?

15 In what ways do the newspapers in your community promote better health? obstruct improvement in health?

16 What changes in your conduct or habits have resulted from anything you have learned about health? from the services of school-health inspection? from anything done by your physician?

17 Why is it necessary to have Federal health service in addition to what the different states and cities are doing?

18 What diseases have been of diminishing importance in your community during the past ten years? What brought about the change?

19 What diseases have been causing more injury in your community during the past ten years? What brought about the change?

1. Do all things exist for the use of man?
2. What do people need besides food, clothing and shelter?
3. Are people better off today than they were in the past?
4. Are people better off under our kind of civilization than they are in simpler cultures?
5. How can we make better use of our resources?
6. If there is overpopulation for other species, can there not also be for man?
7. Can we produce enough to supply everybody's needs?
8. Can our country support a larger population?
9. Should we not be better off if our population were smaller?
10. Should we be better off if we tried to live on what we have without importing or exporting?
11. Is there not a necessary limit to the earth's human population?

Under simple conditions of living people accumulate very few material things. It takes about all the time there is to get the bare necessities and to fight enemies of one kind or another. The only surplus is likely to consist of weapons, simple tools, and trophies of the chase or of war.

With increasing division of labor and with the growth of agriculture, industry and commerce, more and more is produced. It becomes possible to construct more permanent buildings and bridges, ships and roads. People can store up large accumulations of food, cloth, fuel, tools, raw materials, ornaments. These usable objects and materials constitute a people's wealth—the physical basis of their welfare.

In considering the wealth of a people we sometimes include all the natural resources, such as fertile soils, minerals, forests, waterfalls, wild life of land and water, and so on. All these things can be converted into usable wealth by means of people's skill and science. How much of our material welfare depends upon living things? How far does our control of material wealth depend upon our understanding of life—our biology?

How Has Science Changed Our Management of the Earth?

Undermining Ourselves[1] Ages ago men learned that the land upon which they dwelt is the very source of their livelihood, and not merely standing room. By becoming farmers men found ways to obtain food with more certainty and from a smaller area. But the more effectively they raised and removed crops, the more quickly did they exhaust the soil, sometimes literally

[1]See No. 1, p. 656.

forcing themselves off the face of the earth. By mishandling the soil and its living cover man has, in fact, made vast stretches of the earth's surface worthless. And every year, in various parts of the world, millions of acres are being ruined.

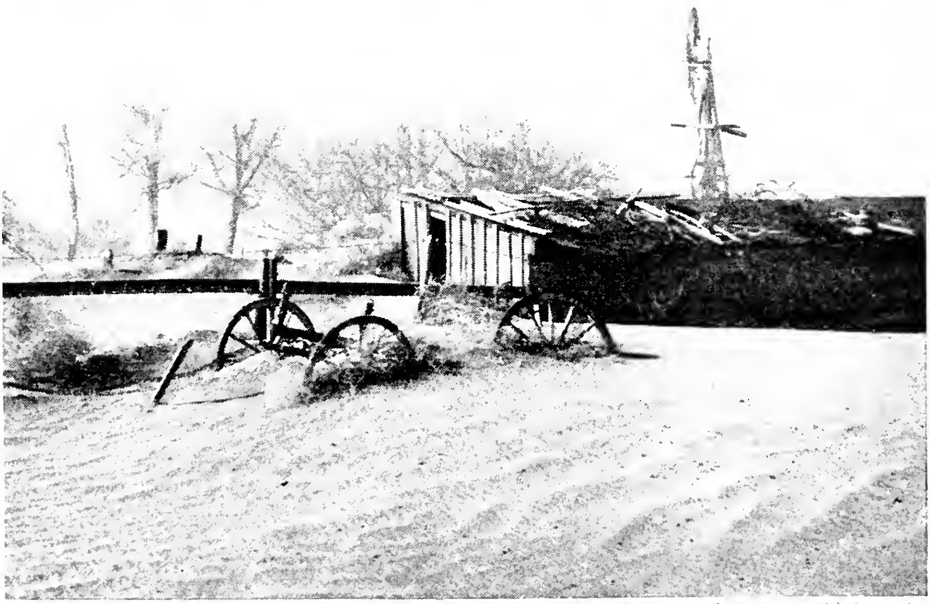
The good earth of our Great Plains, stretching from Montana and the Dakotas to the middle of Texas, had for centuries yielded only grass to feed the bison, and so maintained a sparse and scattered Indian population. Farmers moving westward after the Civil War hoped that their hard work on this land would furnish abundance for their families. The flat lands would be easy to work. In the course of some sixty years large-crop farming developed rapidly. There were good years and poor years, of course. But as years went by, the earth came to yield less and less to man's efforts. By 1938 millions of acres had become so changed that they could no longer support the population that had been depending upon them (see illustration opposite).

The Great Plains land and farms, as well as millions of acres in other parts of the country, were destroyed in part by man's interfering with the natural relationships between living things and the underlying soil and waters. They were destroyed in part by a working of the soil which we have called *mining*—carrying off as fast as possible whatever is of value. We could, of course, replace the essential food-making minerals of the soil with materials brought from other regions. But we had also replaced the perennial grasses, which had in the past bound together the particles of the soil, with cultivated annuals. And in this way we exposed the surface of the earth to the destructive action of wind and water (see illustration, p. 644).

Fifteen million acres can no longer be plowed. On most of the range lands production has declined from 25 to 50 per cent in some places and by as much as 75 per cent in other parts. Moreover, these acres can be of value in the future only if we change radically our ways of treating and using them. It is not exactly a case of killing the goose that laid the golden eggs, for the acres are still there. That is, the goose is not quite dead. But if she is left to herself, she will not revive fast enough to be of help to us for at least a generation or two.

The Soil's Fertility From ancient times people traditionally saved household and farm wastes for manuring their fields (see page 150). It was only in the first half of the last century that the foundations of soil chemistry were laid by the researches of a Frenchman, Nicholas de Saussure (1767–1845); a German, Justus von Liebig (1803–1873); and an Englishman, John Lawes (1814–1900). From their work we learned to restore to the soil the essential chemical and physical conditions.

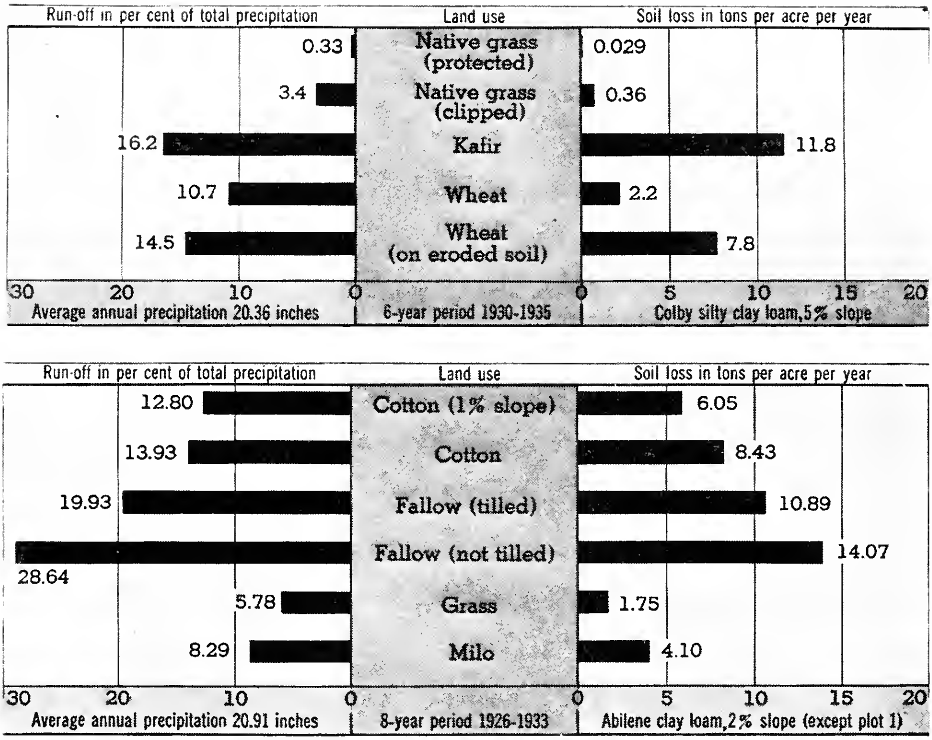
Working the soil physically to get the best results also had to be learned, at first through trial and error, and later through systematic research and experimenting. Throwing seeds on the ground would yield something. Scratch-



Soil Conservation Service; Farm Security Administration

FARMS BLOWN OFF THE EARTH

Without waiting for the great storms, farmers are constantly letting the sources of our living be blown and washed away. The wind blows the creative soil from a farm, and it is gone forever; but the shower of dust continues to destroy whatever it covers



USING THE LAND AND LOSING THE SOIL AND WATER

The rains and snows run off the land more or less rapidly and thoroughly, according to the way the soil is used and treated. Modern methods of extracting from the earth its precious yield, as quickly as possible, and more than the inhabitants can use, sometimes destroy the very earth upon which we depend

ing the old growth away with a stick before scattering the seeds would yield more. Man learned to scratch deeper. He hitched an ox or a camel to a heavier stick. Later he used horses. He put a steel edge on his plow. Finally, all merely mechanical work of man and beast is transferred to machinery.

By using more and more machinery in cultivating, weeding, watering, harvesting, and so on, a small crew of skilled operators is able to work twenty or thirty times as much land as they could with horses and their own labor (see illustration, p. 646). Through such intensification of effort, combined with other improvements in practice largely based on biological knowledge, men were able to increase the output per worker and also the yield per acre up to several hundred per cent. But in this progress they failed to note that there is a point beyond which bigger and bigger does not necessarily mean better and better. For by using more powerful machinery for working the soil, they came to plow deeper and deeper and so defeated their own purposes. Turning the soil over too completely covered the stubble and

roots of the previous crop and exposed the new soil to wind and water. This deep soil, brought to the surface, lacks the product of organic change going on near the surface, and it also fails to hold together mechanically. Such deep plowing has probably contributed to the ruin of the soil in many parts of the flat farm country.

From better ways of working the soil we learned also how to conserve the soil, and eventually to keep it from becoming exhausted. Millions of farms have been allowed to deteriorate so that they can hardly be reclaimed. At the same time, we can see other farms continuing to yield year after year, in spite of more intensive working.

Earth and Water We depend upon rain for the growth of plants; yet every year the rain washes tons of earth into streams and rivers. The quantity of earth carried down to the sea every year is estimated to be worth over a billion dollars. Not only is this a direct loss of agricultural resources, but it also interferes with the navigation of streams and chokes the harbors. We have to spend millions of dollars every year to dredge rivers and harbors to remove this soil. As we saw, it is the mining of timber that has been largely responsible for disturbing the water balance and for injuring the soil, by destroying the absorbent forest floor (see pages 589 ff.). Conversely, reclaiming desert lands depends upon supplies of water from regions that are continually covered with forest.

The Forest and Water[1] Every year, as the snows on the hills begin to melt, the water rushes down the hillsides in the deforested regions. The streams overflow their banks, and the torrents tear down and destroy everything in their path. The annual damage done by floods in this country is estimated to be equal to one hundred million dollars. This takes no account of the destruction of human life that often accompanies the floods.

For agricultural purposes, water must be had in abundance throughout the summer. The destruction of forests in one region has often resulted in the ruin of agriculture and in the migration of people in a distant valley. Streams that depend upon deforested areas for their water will be too full in the spring and will run too low in the summer. The forest influences navigation on the larger streams in two ways: (1) it maintains a steady flow of water, and (2) it prevents the filling up of a stream with soil.

Water Power As our industries expand, we are pressed to find sources of energy for driving our machines. The consumption of coal has increased so rapidly that the earth's supply threatens to be exhausted. Oil, which is also limited in quantity, seems to be more valuable for use in cars, trucks, airplanes and boats. Water power seems to be the only source of energy that is constantly renewing itself. But to maintain the service of waterfalls, we must be sure that the water supply will be steady. And this in turn depends upon

[1]See No. 2, p. 656.

Soil Conservation Service

BETTER WAYS OF SCRATCHING THE EARTH

The improvements in agriculture since the abolition of slavery have exceeded all the improvements made in over two thousand years before. Fifty years after Thomas Jefferson proposed a metal plow and the common school, we were still using wooden plows generally and were just thinking of starting common schools for all

the forest.[1] Soil and water can be a permanent source of wealth for human beings, but only if they are worked in ways that preserve their usefulness.

What Are the Limits to Man's Production of Wealth?

Basic Needs[2] When we compare different nations or different periods in history, we find that people have the same basic needs always and everywhere. They must have food, and they must protect themselves against various kinds of dangers. Many different kinds of materials serve as food in different parts of the world. And with modern means of transportation and preservation, many different kinds of food can be had by people in modern cities and towns. Shelters vary, according to climate and according to materials available. In some regions people wear very little clothing of any kind, aside from ornaments. In other regions they expose very little of their skins out of doors.

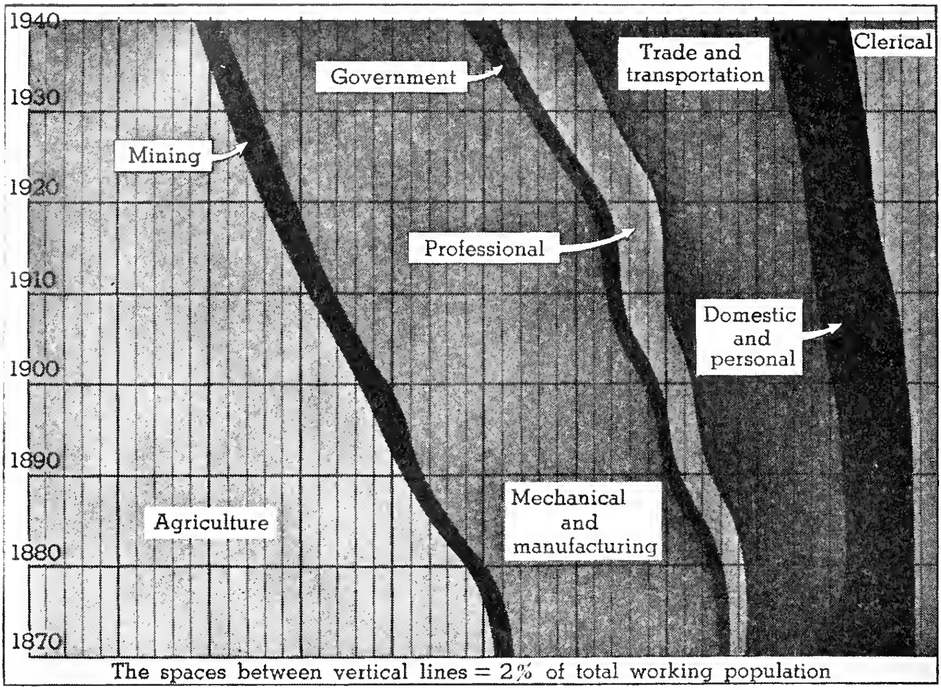
Supplies of food material, fibers, timber, furs, drug plants, and other usable plant and animal products have been made available in ever-larger quantities through our new ways of working. These new technologies depend upon using scientific methods of solving problems. They have made it possible for mankind to increase rapidly in numbers and to spread over the face of the earth. Regions that were in the past uninhabitable have been made into comfortable and healthy communities. We can assure our entire population of whatever it needs of organic materials with a smaller fraction of workers engaged in agriculture and animal husbandry (see illustration, p. 648).

Human beings are unique among all living species in the many ways in which they make use of materials for other purposes than "keeping alive". Paper, for example, is a necessity in every industry, business, government, sport. We use it not only for books and journals, or for correspondence and records and accounting, but also for lining our rooms, insulating our walls and roofs, wrapping our groceries and other purchases, and for making money and washtubs and carwheels. We similarly use plant and animal fibers, originally gathered or raised for clothing, in entirely new ways—cordage, burlap, sailcloth, airplane wings, bunting and parachutes.

Human Needs These many new uses, and the "needs" which they serve, are, of course, incidental to man's other peculiar traits—his distinct kind of brain and hands, for example, his sociability and language, his imagination and self-consciousness. Because of these distinctive traits human beings have "needs" that other animals do not have. In addition to being hungry like other species, man can be anxious about the uncertainty of the next meal. Human beings need to feel secure. Accordingly, they often pile up much more

[1] Since all coal consists of the modified remains of ancient vegetation, burning coal as fuel still means drawing upon the forest, though not the forest of our own times.

[2] See Nos. 3, 4, 5 and 6, p. 656.



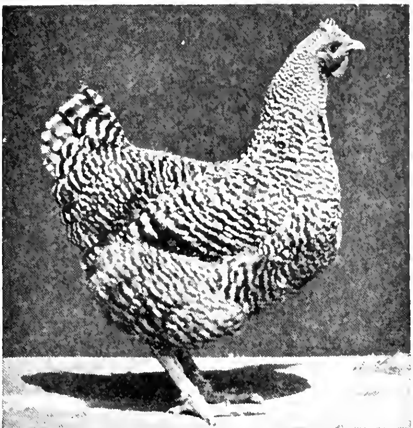
CHANGING PROPORTIONS OF THE ECONOMIC ELEMENTS OF THE POPULATION

When the Constitution of the United States was adopted, 19 persons were engaged in agriculture for each person in other kinds of work. It took that much of our total labor power to keep the population supplied with food and organic raw materials for clothing and shelter. At the beginning of the Second World War 19 persons engaged in agriculture could maintain 80 in other kinds of work. What brought about these changes? What further changes are likely?

than they can use. Where trade and commerce are established, men try to accumulate "wealth", or else money which can be exchanged for usable things.

Because of their social disposition human beings need to feel that they belong in a particular set, or have a place in the community. To meet this need they sometimes wear special garments or ornaments to tell the world to what set they belong or how important they are—the old school tie, for example, or a sorority pin. We put up badges and signs to assure ourselves that we rate. More important than signs and labels (which after all may be false, or merely "put on"), we need to make genuine impressions upon one another and upon the materials around us. Above all, each individual needs to feel his own power over things or over others in order to feel secure and important.

Men make things they need or things they want to have or use—houses, furniture, pies, roads, garments, tools, vehicles. But they make also dolls and masks, pictures and drums, model airplanes, and many, many more fancy



High-breed hen

Scrub hen

EGG PRODUCTION IN U.S.A.	Each 0=10 eggs
Average egg production per hen -- 1900	00000 000
Average egg production per hen -- 1942	00000 00000 0
Average egg production of 10 superior hens	00000 00000 00000 00000 00000 00
Average egg production of 10 sets of daughters of these hens (10 flocks of 232 hens)	Average per flock 00000 00000 00000 00000 0000 to 00000 00000 00000 00000 00000 000

IMPROVEMENT IN EGG PRODUCTION IN THREE SETS OF EXPERIMENTS

	Australia		England		Connecticut, U.S.A.	
	1903	1935	1922	1930	1915	1933
Eggs per hen (average)	171 173	199 200	186	192	159 169 157	235 217 220

MAKING HENS PAY FOR THEIR KEEP

Getting 100 eggs a year for each hen, or getting over 200 eggs weighing at least 2 ounces each, depends not so much upon the amount of muscular work one does as upon the intelligence used in supplying suitable food and living quarters, in protecting against enemies and parasites and in selecting the stock

lamp shades and foot stools than we ever have a chance to use. In making such things that are not "necessary" the individual does two things: He asserts himself as a person; he impresses himself upon the material world, beyond his hunger or thirst or need for shelter. This is the artist or artisan in man. And

he assures himself of his power by assuring others of his cleverness or worth. He needs to feel that he counts.

These creations embody man's imagination and ingenuity. That is why we are always interested not only in what we ourselves make, but in what others make. We admire the handiwork of the ancients and of faraway peoples, quite aside from any question of its beauty or usefulness. We like to gaze at collections of human product in museums and galleries and market-places. We like window-shopping. Man is a maker. Having to do and to make is quite as much a need as having to eat or to keep warm.

Human Power Because of this restless drive to assure himself and his fellows that he is quite all right, man is constantly using up more and more of the materials around him. He is also accumulating surpluses that are never of any use—except to show that somebody was smart enough to accumulate larger heaps than others. Modern science and technology—which developed more rapidly in the mechanical arts and in chemistry than they did in the biological fields—have enabled us to make more and more things. That means also to use up still more and more materials. These heaps of things are the outward sign of our power over nature, and they furnish us much satisfaction.

The tremendous productivity of modern industry should yield a sense of security; for we are now able to produce all we need—nobody need ever suffer want. We are able to produce an abundance through only a fraction of our traditional effort; more and more men and women can therefore be free to enjoy leisure time. More and more men and women may be free to follow special interests—music, art, science, exploration, whatever the heart desires (see page 648). Truly science has given us great abundance and vast powers.

In spite of our increased productivity, which has been tremendously expanded during the Second World War, people continue to be overworked. Large sections in every country continue to be ill fed, ill clothed, ill housed. People remain anxious about what they have, and fear want. They are insecure and fear their neighbors as possible thieves.

The Sources of New Powers We have seen that these powers come from increasing division of labor, which enables us to use the great variety of talents in human beings to the utmost (see page 529). These subdivisions remove more and more of us, as "consumers", from the plans and processes of production, while they remove the individual workers farther and farther from the finished product (see page 530). Millions of men and women have learned to control vast accumulations of energy, or to direct the movements of large numbers of persons, by performing rather simple operations. A child can shift a traffic signal and make hundreds of cars come to a stop. A fool can pull a false alarm and throw hundreds into a panic. A man makes some marks on a piece of paper, and hundreds of families in another state lose their chance to make a living.

Year	Milk produced per cow
1870	12,681 lb
1880	18,000 lb
1888	30,318 lb

AVERAGE YIELD OF ALL HERDS IN U. S. A. FOR FORTY YEAR PERIOD

Milk - 4000 lb per year

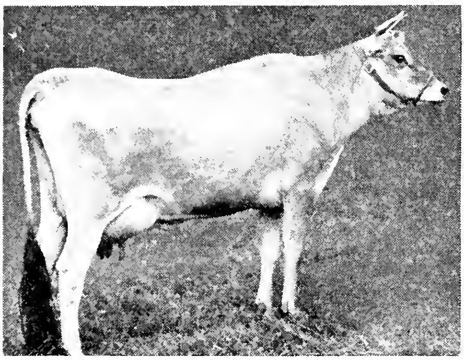
Butterfat - 170 lb per year

AVERAGE YIELD OF DAIRY COWS AT BEGINNING OF CENTURY

7500 lb milk per year

322 lb butterfat, the record yield in 1903

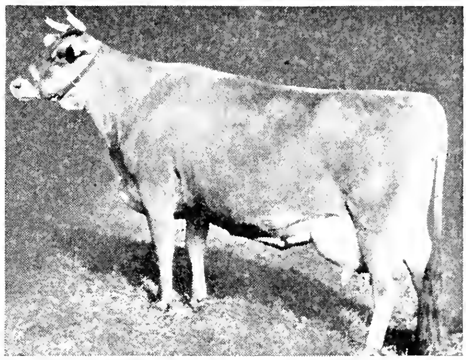
TODAY'S RECORDS FOR JERSEY COWS SHOW



A "POOR" JERSEY YIELDS

11,000 lb milk per year

530 lb butterfat per year



AN "EXCELLENT" JERSEY YIELDS

14,837 lb milk per year

750 lb butterfat per year

SELECTIVE BREEDING IMPOVES BUTTERFAT YIELD

12 selected cows	319 lb	Average butterfat yield
11 daughters	375 lb	
11 other daughters	476 lb	

American Jersey Cattle Club

MORE MILK FOR LESS WORK

One of the most effective ways of saving labor in producing the nation's necessary food is that of improving the breeds of plants and animals

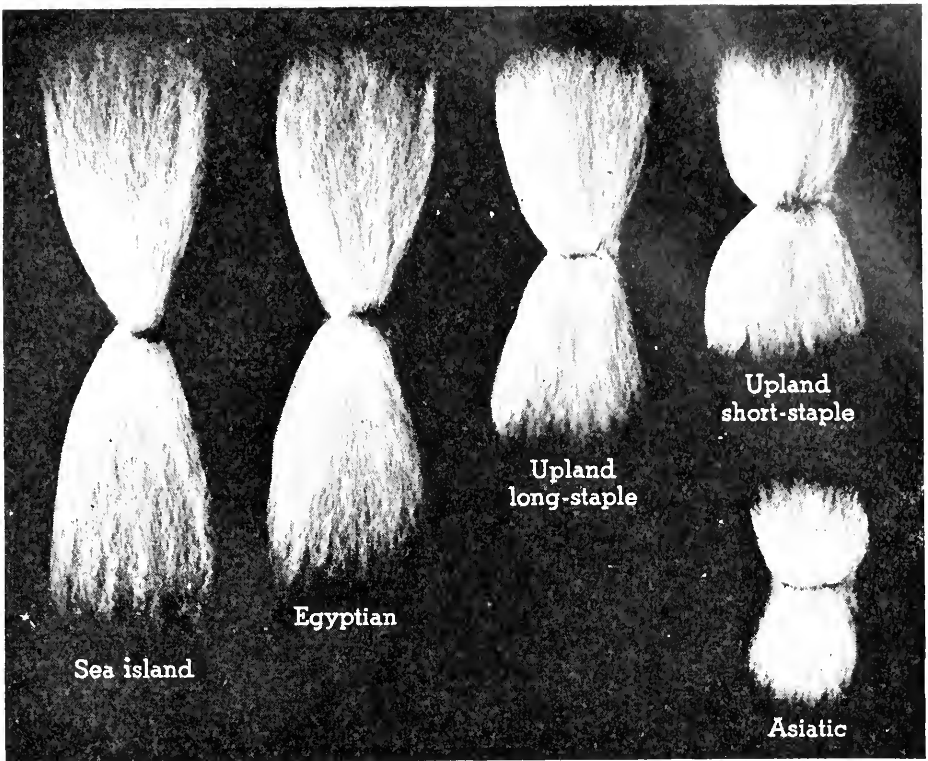
The powers which such individuals exercise are real and effective. But we too often forget that these powers do not properly belong to the individuals who push buttons or make the special marks on paper. These powers have been brought together by hundreds of persons, from widely separated areas, and stored in the comparatively small machines which particular individuals operate. No scientist or engineer could, by himself, either make or use such powerful devices—a telephone system, for example, or a printing press, or a textile mill. Nor could any individual—by himself—use such powers. The press is useful only because hundreds of persons are interested in reading the same book or paper. The telephone is useful only if thousands of people, scattered over a large territory, are interested in communicating with each other. If you had a whole factory to work or play with—by yourself—it would not add much to your control over your environment.

Any person standing at a switch and making one train go along one track and the next along another track may get the notion that he is doing it all himself. Many individuals do in actual life control power in much that way. And they grow into the conceit that it is theirs to do with as they like. But it is *our* power. It will continue to grow, and it will continue to serve mankind, only as we are satisfied to use it for common purposes, rather than for the benefit of the individual who happens to be standing at the switch, or at the traffic signal.

Human power has grown by increasing numberless special skills and special devices which are of use to those who have them *only because others need them.* A doctor cannot make a living by using his medical knowledge on his own body or on his family. A cotton-grower cannot live on cotton, nor the tanner on his product. The power which comes from division of labor and exchange of services is socially created power—that is, power created by people living together. And the power can benefit human beings only as it is put to work through co-ordinated and co-operative effort; only socially is it usable.

Interdependence The advancement of science has been accompanied by a rapid growth of cities in population and wealth. These changes have been so striking that many of us have assumed that by sending everybody into the city we can assure abundance for everybody. The appearance, however, is misleading. In a city like New York or Chicago several thousand persons can indeed live on a square mile of land, but only because our division of labor and our highly perfected means of transportation and communication enable us to bring them the organic materials essential for life.

Under the best agricultural practices it would take thousands of acres and thousands of rural workers and transportation workers to supply food to even a small city. In a state like Connecticut or in a country like England the population can continue to live only so long as vast quantities of fresh and preserved foods continue to be brought in from distant points. The people living in



United States Bureau of Plant Industry

INCREASING YIELD WITH LESS EFFORT

For the same amount of work in the fields, it is possible to raise cotton that will ripen in time to escape damage by the boll weevil, which at one time destroyed 30 per cent of the crop in a year; to raise a variety that resists the wilt, a disease which formerly destroyed entire crops; and to produce a fiber superior to the best available forty years ago

England could, if necessary, raise on their land sufficient food to maintain themselves. They could do so, however, only by replacing a large part of their idle lands or deer-parks with farms and by releasing industrial workers for farm work.

Man's competitors for the produce of the earth are too numerous and too elusive to be fought by any person singlehanded. Our greatest successes have come from joint efforts through a strategy based on knowing more about the enemy than he can possibly understand about us.

Limitations of Self-sufficiency Our use of science for increasing production has gone hand in hand with more extensive commerce within every country and more extensive international trade. Each region can develop intensively whatever special resource it has—iron in one place, sulfur in another, timber somewhere else, or fish—and send it off to other parts of the

world, in exchange for a great variety of useful materials and objects such as it never could produce itself. Portions of the earth which could not otherwise yield its inhabitants a livelihood have thus been made serviceable. A tremendous amount of navigation and railroading and trucking has grown up. There has also, however, grown up a very complex scheme of relationships in which every civilized country depends for its continuous well-being upon other parts of the world. Under such conditions, hardly any nation can be self-sufficient.

The colonial system of modern times has been developing for several centuries as a means of assuring certain European countries adequate supplies of raw materials from backward countries. This arrangement led repeatedly to wars for more territory or for territory that could furnish particular kinds of materials, and it produced a system of competing and conflicting empires. People living in those backward countries, and people living in countries that were without colonies, found it hard to understand why the more powerful nations could not mind their own business. But in a country at war today everybody realizes how dependent we are upon other countries for a multitude of supplies that we cannot produce ourselves.

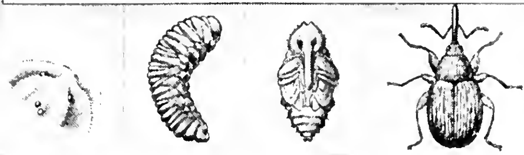
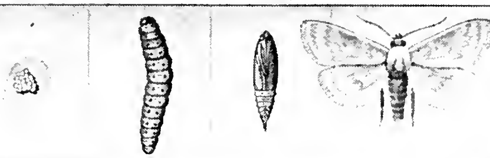
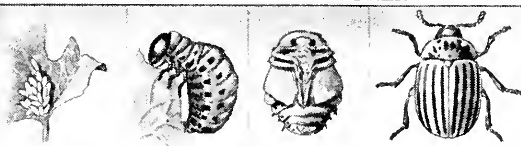
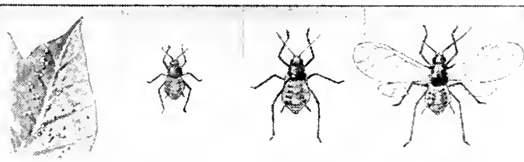
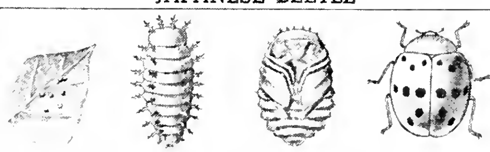
Between the First World War and the Second World War, statesmen everywhere played with the idea of making their own countries self-sufficient—just in case. The British Commonwealth of Nations established trade agreements that would assure the entire group practically all kinds of materials needed for modern living, but no single nation in the group could be self-sufficient. The forty-eight states of the continental part of the United States have a great range of mineral, plant and animal resources, but no one state can be self-sufficient, nor can the entire Union. The Russian Union of Soviet Socialist Republics covers an even greater variety of soils and climates and minerals and living forms, and was aiming at self-sufficiency before the Second World War. The Germans had lost their colonial empire and were attempting to develop their chemical industries so as to produce substitutes for the rubber and oil and fats that they were unable to obtain.

Whatever the benefits of modern civilization, they would almost of necessity be lost by any people that persisted in being self-sufficient—in living by itself. On the contrary, it is getting to be impossible to maintain a scientific civilization in any part of the world without extending the benefits to all people everywhere.

In Brief

Men use more materials and objects to supply food, clothing and shelter than for all other needs combined.

The materials used in connection with the care of the body in health as in disease are derived largely from plants and animals.

Average annual loss	LIFE STAGES OF INSECT EGG LARVA PUPA ADULT	Methods of checking
Damage to cotton crop - $118,000,000	 COTTON BOLL WEEVIL	Early-ripening varieties of plants to beat life cycle of weevil Burn stalks
Damage to corn crop - $17,000,000	 EUROPEAN CORN BORER	Destruction of infested stalks below ground Late fall plowing of stubble Ensilage for stalks
Damage to potato crop - $16,500,000	 COLORADO POTATO BEETLE	Poison sprays and powders (Effective against both larvae and adults)
Damage to grain crops - $13,000,000	 HESSIAN FLY	Planting after fly-free period Burning stubble Crop rotation
Damage to cotton crop - $3,000,000	 COTTON APHID	Poison sprays and powders (Contact sprays most effective)
Damage to orchards, truck crops, trees, etc. $2,700,000	 JAPANESE BEETLE	Poison sprays and powders Capture in traps (effective for adults only)
Damage to bean crops - $1,275,000	 MEXICAN BEAN BEETLE	Poison sprays and powders (Effective against both larvae and adults)

Streams depending upon deforested areas for their water are too full in the spring and run too low in the summer; the destruction of forests in one region has often resulted in the ruin of agriculture and the displacement of peoples in a distant valley.

Soil washed away by water is not only a direct loss of agricultural resources; it also interferes with the navigation of streams and with conditions of harbors.

With the abundance made possible by science, further growth and enrichment of populations seem to be limited by our clinging to attitudes which belong to simpler modes of living—attitudes of mutual suspicion and conflict among men and among tribes.

EXPLORATIONS AND PROJECTS

1 To learn of the extent to which erosion is being and can be controlled, read and report findings obtained from various government publications.[1]

2 To find the extent to which our forest resources have been and are being exploited, investigate the changing forest areas within the United States. Find out what proportion of our original forests still remains; whether forest areas are being depleted at the present time; and what is being done to conserve and to replace forests.

3 To find out how staple crops are produced, investigate the growing, storage and marketing of such crops as corn, wheat, oats, cotton, tobacco, clover, alfalfa, potatoes, apples, oranges, grapefruit, and the various vegetable crops. Prepare a written report on your findings.

4 To find out how various meat, dairy and poultry products are produced, investigate the feeding, breeding, care and marketing of beef cattle, dairy cattle, hogs, sheep, chickens, and the like. Prepare a written report of your findings.

5 To learn how to can fruits, vegetables and meats, try packing some as described in Farmers' Bulletin No. 1762, entitled *Home Canning of Fruits, Vegetables, and Meats*, or in other available descriptions of the process. Describe the essential steps in the canning of foods.

6 To learn about the new uses of agricultural products in industry, investigate the many commercial uses of various products manufactured from soybeans, from cotton seeds, from corn, from peanuts, from milk, and from other agricultural products.

QUESTIONS

1 What are the outstanding needs for which man uses other living things and their products?

2 What kinds of plant or animal products are most useful in meeting the primary needs of man?

[1]Report of the Mississippi Valley Committee of the Public Works Administration, pp. 61–68, 119–126. United States Department of Agriculture Miscellaneous Publication No. 321, entitled *To Hold This Soil*. United States Department of Agriculture Yearbook, 1937, entitled *Soils and Men*.

3 For what other purpose does man use plants and animals?

4 How does a feeling of security or insecurity with regard to these primary needs influence health and effective living?

5 How can forest conditions in one region influence the interests of people in another region?

6 How do any particular forests influence conditions in your region?

7 What damage results from forest fires besides the destruction of trees?

8 What lands in your region would be available for forest without loss to farming? When is it better to use land for trees than for agriculture?

9 What biological ideas have helped to enrich our people?

10 What are the advantages of living in a self-sufficient nation? What are the disadvantages?

11 What does international trade contribute to a people besides making imports available?

1. Do all living things feel pain and pleasure?
2. Can other animals besides human beings feel happy or unhappy?
3. Why do some people seem to be more consistently cheerful, or more consistently unhappy, than others?
4. What conditions are likely to increase human happiness?
5. Does happiness depend upon circumstances or upon one's nature?
6. Can people be happy if they are not in good health?
7. Are children happier than adults?
8. How does being civilized make people happier than savages are?
9. Why is it said that more knowledge means more sorrow?
10. If wealth does not ensure happiness, why do people try so hard to get it?

A baby gets what he needs when he needs it. He is protected from harm. His comfort is looked after. Nothing worries him. He need not exert himself. Could anyone be happier? From this point of view, the pillow on which the baby lies may be still happier. It has no needs. Hardly anything can hurt it. It can experience no discomfort. It can neither exert itself nor worry. Many of us feel at times that we should like to change places with a baby. Hardly anyone would want to change places with a pillow.

The most complex animals are the most sensitive to stimuli. They are accordingly able to feel the most pain—but also the most pleasure. Man, with his exceptional intelligence, finds ways to reduce sickness and pain, to lengthen life. He has managed to increase the margin of free time and energy, to use as he likes. He can enjoy life, not merely make a living. He can carry on activities that are distinctly human. He finds satisfactions that are distinctly human.

But is man today better off than his ancestors were? Are people in scientific countries any happier than those in backward countries?

Just What Is Happiness?

Pain and Pleasure[1] The most "real" of all experiences are the feelings of pleasure or of pain which accompany our sensations and our activities. These feelings influence all our actions. Everybody wants to avoid pain and to get pleasure, more and more pleasure. Yet "pleasure" is not the same as happiness. Indeed, the mother of a new baby insists she is very happy while her physical pains are quite severe. A player who has been hurt in a game says that he is happy over the outcome. But the immediate practical goals in the pursuit of happiness are largely to satisfy desires and to avoid or reduce pain.

[1]See No. 1, p. 673.

Pain and Privation Man has succeeded pretty well in assuring himself of the basic necessities, through his fight against natural forces and enemies. Actual hunger has been reduced, even if many are still undernourished. We no longer accept starvation as a regular part of life, as people in many parts of the world did in the past, and still do in some. Probably fewer people today suffer from extreme cold or exposure, from bad housing and inadequate clothing. Yet here, again, our population is far from adequately supplied with the necessities for modest but safe living.

We have also reduced the suffering due to many preventable diseases and to infections that sometimes follow bruises, cuts, the stings and bites of animals, childbearing, surgical operations.

From ancient times people have been seeking ways of overcoming physical pain. Opium, which is prepared from the latex of the seed-capsule of the Oriental poppy, has been used to produce drowsiness and stupor. For many centuries people have used alcohol to "cheer" them up and to "drown their sorrows". Other drugs and devices have been used in efforts to reduce suffering. Generally speaking, however, physical pain has, until comparatively recently, been accepted as in the nature of things, as part of man's lot. Only since 1800 have people begun to consider seriously the idea that physical pain could be attacked systematically, like any other human problem. In that year Humphry Davy (1778–1829) suggested that pain might be deadened by the use of nitrous oxide, or "laughing gas"—which had been discovered in 1776 by Joseph Priestley (1733–1804). In about forty years nitrous oxide and later ether came into use for destroying pain during the pulling of teeth. Gradually it became customary to prevent pain in all surgical operations by using *anesthesia*, a name suggested by Dr. Oliver Wendell Holmes and meaning "lack of sensation".

Joseph Y. Simpson (1811–1870), a Scottish surgeon, first used chloroform to avoid pains in childbirth. Many groups opposed this on "religious" grounds. They did not argue that chloroform might be injurious, but were convinced that "God intended" woman to bear children in pain. When Queen Victoria gave birth to a child with the help of chloroform, the opposition began to die down.

After the middle of the century it was discovered that *cocain* destroys sensitivity to pain in the tissues into which it has been injected. Later it came into use as a *local* anesthetic. As a result of modern chemical and physiological studies, we now have various preparations that ease or completely overcome physical pain, and that without destroying consciousness. We have perhaps all read about the surgeon whose leg was crushed in an accident and who, after receiving the suitable "anesthesia", directed the amputation and conversed with the other surgeons. The drug blocks some of the afferent nerves but leaves certain efferent paths and the higher brain centers unaffected.

Positive Needs Reducing pain and privation or preventing sickness and physical suffering is but part of our problem. We want positive satisfactions and pleasures. As human beings, however, we want more. "Life is more than meat." We want to do a thousand things that are not necessary to us as organisms, but that are necessary for our comfort and satisfaction—and our happiness—as human beings. To be happy man must have a chance to go after what he wants, whether he ever attains it or not. Perhaps that is what is meant by the right to the "pursuit of happiness"—rather than the right to happiness.

Values[1] We cannot compare satisfactions felt by different persons, nor measure degrees of satisfaction that we ourselves feel. Yet we are constantly making choices or decisions in the effort to increase our pleasures. With experience, we learn that some of life's offerings are not worth much to us. But we will go out of our way to see a particular game or exhibit, to hear a particular composition or performer, to take part in a particular meeting or athletic event. Our strivings are for *values*, and each one has to learn what is of most worth to him. We learn also to consider what is of greatest worth in the long run.

How Do Our Needs Differ from Those of Other Species?

Obstacles to Satisfaction Whatever interferes with our efforts to satisfy our wants is itself a cause of dissatisfaction or unhappiness. Being blocked or frustrated arouses anger or sulking or sour temper or resentment. One may come to dislike particular persons or situations that he associates with the obstacle. These unhappy feelings seem to come in addition to the chemical or physical results of any privations or injuries.

Again, almost any obstacle may act as a challenge. We climb a mountain just for the fun of getting to the top. We jump over a fence instead of going through the gate. We devise obstacle races: clearing a hurdle seems to be more important than merely getting to the other side. Men fight not only for what they must have. They are especially aroused to fighting whatever stands in the way of their purpose.

Increasing the Range of Needs Human beings remember and imagine more than other species. They are exceptional hunters and prowlers. They pry into hidden corners. They poke their fingers into hornets' nests or their feet into the mud. We say that they are *curious*. They thus get into new situations with which they are unable to cope. They taste what never had been eaten by human beings before. They pick things to pieces. As human beings, we seem unable to let well enough alone. Prying, exploring, experimenting, analyzing, often lead to missteps, mistakes, or tragic blunders. But it is only by yielding to this curiosity and experiencing mistakes that man makes progress.

[1]See Nos. 2 and 3, pp. 673 and 674.

Gendreau

ADVENTURING AND EXPLORING

Why does anybody bother to reach the south pole or the top of a high mountain? What's there besides snow when the goal is reached? Why hunt for tigers or poisonous snakes, or experiment with deadly bacteria?

In general, then, we are disposed to wonder, to explore, to inquire, although we are also commonly held back by fear. In time some learn to explore cautiously, knowing dangers. Men have extended their explorations in all directions on the surface of the earth, and into the waters and into the air. We have wondered about the remotest reaches in space and in time, about the very constitution of the universe and of matter. We have wondered how the things we see came into being. What makes things happen as they do? What will happen in the future?

Substitute Values Our imagination not only creates new needs, but furnishes types of satisfaction that are probably different from those of other species. We cannot all go out to explore the bottom of the sea, for example, or the south pole. We may, however, share—in imagination—some of the excitement and satisfaction of hunting big game, of discovering new regions or new kinds of human beings. We read about such adventures, or look at pictures made by others, or hear someone describe his experiences. We are able to throw ourselves, in imagination, into new scenes, new situations. We share the excitement of the players in a game that we are watching, or of a boxing or wrestling match. We "put ourselves in the place" of other persons. And to the extent that we do so we get the corresponding feelings.

We are able to enjoy *vicariously*—through substitution—the satisfactions and excitements and adventures of other people, to get the benefits of make-believe. But we can also feel the anxieties that go with the dangers. We can almost feel the pain of a blow in watching a fight. As we watch a game, are we going to feel more satisfaction or more disappointment? That depends in part at least on the side with which we have *identified* ourselves.

Aesthetic Values[1] In every experience our tastes seem to be rich sources of satisfaction. To enjoy music, works of art, natural objects and scenery, particular types of plays or fiction, the watching of particular games, the company of particular persons, is to add to the fullness of life. What we like means more to us than other things.

The tastes of each person depend in part upon the actual sensitivity of the receptor organs (see pages 284ff.). One person can discriminate shades of color or degrees of illumination much more delicately than another. One can hear several distinct tones between one note on the piano and the next, whereas another cannot tell the difference between B and B flat. For some individuals food is food; enjoying food more means for them merely eating more food. Others, however, are aware of delicate flavors and combinations that are in themselves sources of genuine enjoyment quite aside from the need to appease hunger.

For most of us, differences in taste are largely acquired, within the limitations of the sensory system, our imagination and our intelligence. For example,

[1]See Nos. 4 and 5, p. 674.

Roberts; Keystone

VICARIOUS ENJOYMENT OF PRIMITIVE IMPULSES

Why is it so important to these players what happens to that ball? Why is it so important to the thousands of onlookers? Why is it so important to the hundreds of thousands who listen to the broadcast account, or who read the newspaper reports?

we all like a scene that *recalls* pleasant hours of childhood, or persons we have liked since childhood, or songs that we liked in childhood. In many cases we develop preferences under the influence of people for whom we have high regard. If our hero, at a certain stage in our development, liked artichokes, we learned to like artichokes and to feel superior to those who do not. Or if a person we greatly admired disliked a particular poet or composer, we found it difficult to enjoy that poet or composer.

People of influence in a community or in a school often impose their own likes and dislikes upon others, often indeed without meaning to. Those of us who have no decided preferences are likely to borrow preferences that seem to be approved or in good repute. It is largely for this reason that it is possible to bring about rapid changes in fashions without much regard to what persons of sensitivity and fine discrimination consider in good taste.

Finally, many become accustomed to particular styles in clothing, architecture, table manners, patterns of meals, social customs, and so on, to the point where everything that is different seems to be ugly, wrong, or in poor taste.

WE ALL LOVE BEAUTY

Why do some creations appeal to larger numbers than others do? Why do some continue to be liked for many years, whereas others soon lose their interest?

In general, likings and dislikings, no matter how they have been acquired, play a large role in the pleasures of life on every level of human interest.

Anticipation We may concede that a hungry dog or horse "enjoys" his food. We can even find evidence that the agreeable feelings which an animal may associate with the gratifying of hunger are to a degree anticipated: the dog, for example, moves toward his food with alacrity, he behaves as if he were looking forward to a good time. Human beings, at any rate, derive positive satisfaction from the activities which more or less directly *lead to* the gratifying of desires or the carrying out of purposes.

Every important project involves many disagreeable or even painful details. An animal engaged in a fight will often stick it out against severe strain

and probable suffering. But man alone seems able to plan and persist against difficulties over a long stretch of time. The work of the farmer, for example, continues over many months in anticipation of the harvest.

Anticipation is not all stimulating, however. A mother preparing a meal for the family may be troubled by anxieties instead of enjoying in advance the satisfaction of feeding the hungry ones. She is troubled by uncertainty as to the next day's meals, and can therefore enjoy neither the meal itself nor the preparations for it. Some might say that looking ahead does not help the mother, since it leads her to worry. But she was able to plan and prepare this meal only by looking ahead.

How Does Social Living Influence Happiness?

Learning Restraints We all want to be free to do as we like. Yet the infant would soon perish if he were left to do as he liked. And later we replace what we feel like doing with liking to do something else.

We all learn rather early that some restraints upon our impulses are necessary from the nature of things. The child learns, for example, that he prefers *not* to touch a flame, or to pull the cat's tail, or to grab a knife. But the regulations that other people prescribe for us often seem arbitrary and unreasonable. These *Donts* and *Thou-shalt-nots*—prohibitions and denials—make a child unhappy. Why may I not do as I like? Why may I not eat those apples or that candy? Why may I not stay up longer? Why may I not say what I think about that old Mrs. Sourpuss? Why must I wait for Jimmy?

It is not satisfactory to be told by a larger and stronger person, "Because I said so!" For all one knows to the contrary, the parent or the teacher or the lawmakers might have *said* just the opposite. Indeed, as we grow older, we discover that other teachers, other people's parents, other lawmakers, *have* said just the opposite. It does seem arbitrary. Yet we also learn gradually that at least some of the forbidden acts often bring their natural pains and penalties. In some things, the older people seem to know better. In other cases, forbidden acts deprive us of the friendliness and approval of those we like, or they deprive us of those upon whom we depend for favors or for our comfort. And in still other cases, we feel that we can afford to take a chance: perhaps we shall not get caught this time; or perhaps it will not hurt so much; or perhaps the fun is worth the suffering or penalty. That is, we learn rather early in life to weigh values—our present desires against later consequences.

Becoming Human The infant not only depends upon others from the first for his health and survival; as he grows older he depends increasingly upon others for a multitude of satisfactions and services. He depends upon others for praise and approval, for consolation and encouragement, for understanding and affection.

An infant might indeed be kept by himself in good health for many years but then grow up into an animal that is human in hardly more than form. *Only in the group* does one find the stimulation and guidance which convert him from a little animal into a person. It takes experience with others to learn language, the arts of handling food or common tools, our particular ways of living. Becoming human means becoming a member of a group, with all the satisfactions and helps—and all the interferences too. That is, it involves getting certain benefits—taking; but it means also making adjustments, making allowance, making concessions—giving.

Discovering Ourselves The infant discovers himself partly in what he learns to do with the objects around him. It is fun merely to handle things, move things around, piling up and knocking over, tearing paper or breaking sticks, throwing, scribbling, kneading dough or clay. Gradually the piles he builds up or the markings he makes come to have meaning; they suggest familiar objects; that is a house, that is a tree. The child discovers that he can make—he is a creator! That is tremendously gratifying. The child may never become an artist, a builder, a designer, an architect, a statesman. For the time being, however, the act of creating satisfies his pride, his self-esteem. Now he feels *I do! I make!*

Satisfactions of such an order are important throughout life. Many men and women who have all they want of physical materials, housing, amusements, medical and other special services, yet remain always unsatisfied because they cannot impress themselves directly upon the material world. That is why there is so much interest and value in all kinds of handicraft hobbies and old-fashioned household activities. Through cooking and knitting, through whittling and cabinetmaking, through gardening or furniture-repairing, one may create something to show for his effort. This is especially needed, apparently, by those whose daily work consists of details that become absorbed in products which they never see themselves. One makes a particular series of buttonholes, but never a completed garment. One keeps the working-time in a lumber-yard, but never sees what the lumber is built into.

The individual discovers himself further through the effects which he learns to make upon others. I can scribble something and call it a tree, or a poem, or a poem about a tree. But unless others recognize it about as I intend it, I cannot be quite sure that my work is good, that it has value. For I must have the understanding and approval of others. The friendly encouragement of my parents (who like me and who may be biased) is not enough. I need further the judgment of many others, who appraise my work—and me—at a true worth.

The individual, then, has to express himself by what he does to persons, as well as by what he can do to things. He has to impress others, as well as assert himself. He must draw to himself the regard of others.

We discover the peculiarities of the world around us by trial and error. As we push and pull at things, some objects resist our efforts and others yield. From what happens or fails to happen as we handle things or as we try to make them serve us, we get most of our practical knowledge about matter—hard and soft, heavy and light, tough and tender. And in just the same way we discover our own possibilities and limitations—what we can do with things, how to manage different kinds, how far we can go, and points beyond which we are helpless

Child Study Laboratory, Vassar College

LEARNING BY DOING

Social Sensitivity The developing person wants the approval and regard of those for whom he cares. In childhood this means members of the family, playmates, the neighbors.

The fact that we do care for others and want others to care for us influences our purposes and desires. For we wish to please those whom we like, to help them, to protect them against hurts of all kinds. Accordingly, as human beings, we determine for one another what we consider important, what we strive for, what we value. One does not ask himself whether he should be devoted or loyal to those he likes, or whether he should sacrifice immediate pleasures or control his impulses. We feel loyalty and devotion toward those with whom we identify ourselves. And these feelings determine our actions. What one does "for others" he really does for himself or for that group of which he feels himself a part.

In a group of those who thus give and take, further satisfactions come from *sharing*. We want our friends to know of our achievements, our successes; and we are pleased by the achievements and successes of our friends. In this way pleasures are increased. On the other hand, when we share our disappointments or our sorrows, they become easier to bear. It is en-*cour*-aging—that is, *heart*-ening—to feel that others are with you, that they care for you, that they will back you up. In any case, there is the need to feel that one *belongs*. This is quite as important for one's health and happiness as adequate food or shelter.

Individuals in the family, among friends, or in a club normally feel mutual regard and consideration. The members of such a group do not ask themselves whether they are going to get as much as they give. Each one who truly *belongs* not only is confident that he will get all that is due him but is eager to do everything he can for the others or for the group. The best-integrated

social unit among all kinds of peoples is probably the family. The members of this group are usually bound together by affection. The stronger members protect and help the weaker. Each one exerts himself according to his special abilities or talents. And each one receives according to his special needs. The "equality" within the family does not consist of giving young and old equal quantities of milk or meat, or giving everybody shoes of the same size. It consists of assuring each an equal chance to get what *he* needs or what is best for *him*—within the limits of the common resources—and of assuring each an equal chance to assert himself as a distinct person.

Human Possibilities Each one of us discovers some things that he can do with satisfaction. But each discovers that there are more things which he cannot hope to master. Is he going to get his satisfactions out of what is possible, or will he draw his misery out of what is beyond him? If one is too easily satisfied, he will get relatively little out of his life; he will fail to get the regard of others and of himself in proportion to his capacity to do and to enjoy. On the other hand, if he attempts the impossible, if he is too ambitious, he not only will be disappointed, but will make himself ridiculous.

It is not easy to find our way in the swirling currents and countercurrents to which our own strokes or flounderings contribute. Human life need not be the kind of struggle that goes on in the jungle, but it is still a struggle, and probably always will be. The struggle now, however, is not for each one to dig from the earth and to grasp for himself the bare necessities. Cold and hunger can be met much more simply. The struggle is between one's own feelings and desires—as a person, as one among others—and the demands and pressures put upon him by others.

We have seen that a frustrated infant becomes angry. The individual who is constantly frustrated becomes permanently angry, resentful, full of hatred. And he turns these feelings aggressively against others—against weaker persons, against those he envies or those he holds responsible for his difficulties, against institutions, against all society. A child who fails to make a satisfactory impression upon others feels humiliated. He is tempted to withdraw from others; he wants to be let alone. But at the first chance he may try to make up for his troubles by bullying or attacking weaker children.

Individuals may make a satisfactory adjustment within a small group but find it impossible to fit into a larger community. A club may be merely a group of congenial persons who have something in common and like to be together for carrying on some special activity. There are many social clubs or hobby clubs. On the other hand, the members of such a group may have little to share with the larger community. They may become a "gang". The individuals in such a group have to get the approval and applause of their fellows. But sometimes they do so in ways that are quite objectionable to the rest of the community.

Equality of opportunity
The same kinds and sizes of shoes for all

Equality of responsibility
The same load and the same task for everybody

First come, first served; no favorites
First one down gets all the cream

Each according to his needs

NOTIONS OF DEMOCRACY IN THE FAMILY

We use various slogans to justify our conduct or to explain why we consider some acts right and others wrong. But these slogans often hide inconsiderate or undemocratic acts. Our rules are perhaps not as important as our attitudes

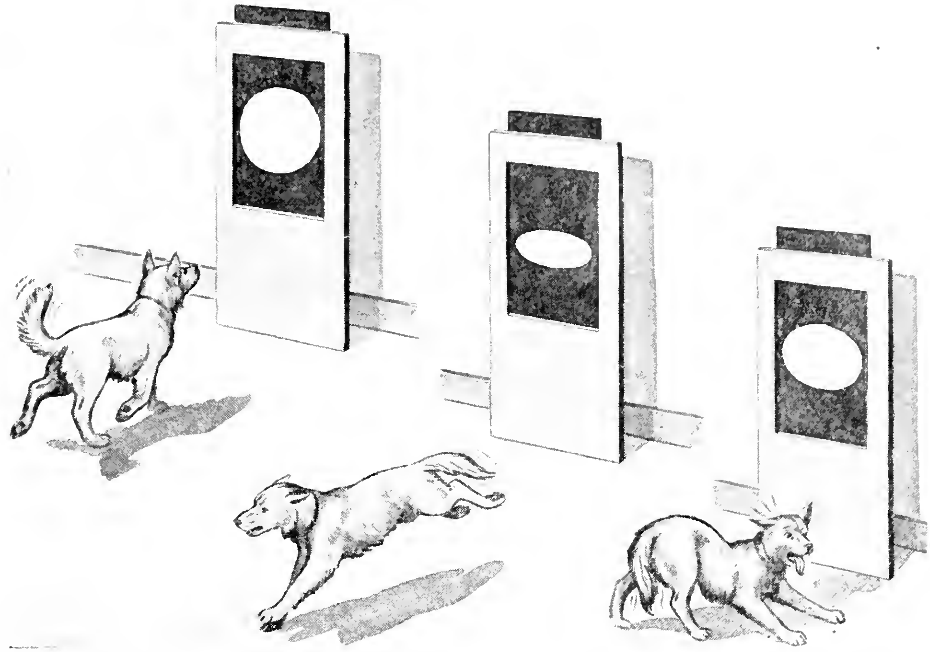
Some individuals fail to mature into independence and self-assurance. An adult who has no suitable ways of getting what he wants among others sometimes continues to use baby tricks. There are men and women, for example, who break into fits of anger or tantrums, who pound the table and shout, or go into hysterics. They have learned no other ways of meeting problems, or of adjusting themselves to other persons.

In modern times we have learned that we can control events increasingly as we come to know more about the nature of the world around us. We can prevent certain diseases altogether. We can reduce many kinds of accidents substantially. We can lengthen life. But our controls over pestilence and plague and food-shortage and physical pain come only from the pooling of experience and knowledge and our practical programs.

In the same way we can reduce our individual anxieties and uncertainties only by pooling our risks and our resources. We are unable to predict when or where death or misfortune will strike. But we can estimate rather closely how many deaths or accidents there will be in a given population for a year or more in advance, or how many days of sickness there will be, or what the chances are that a hailstorm will destroy a crop. Through our insurance systems, whether commercial, co-operative, or public, we divide the burden of disaster. Insurance cannot prevent calamity or death. It can only give the individual that comfortable feeling that he has the backing of the entire group: whatever happens, the immediate needs will receive consideration. The individual feels that he shares, that the odds are not against him.

Inner Conflicts Did you ever see a child hold up the traffic at a party because all the cookies or candies on a plate were equally attractive, so that he could not decide which one to take? Each of us frequently meets a situation in which action is blocked because we wish to turn to the right and to the left at the same time. In extreme cases, a person with such divided purposes becomes unable to carry on the ordinary affairs of life. The condition appears to be not so much inherited or constitutional as acquired; or perhaps it is a relic of a childish state that one has not outgrown. At any rate, similar states have been cultivated in animals experimentally.

The classic experiments were made in Pavlov's laboratory (see page 267). A dog was "conditioned" to come toward a certain spot in the laboratory when a circular disk was illuminated, by the consistent offering of food. He was also conditioned to move in the opposite direction whenever an elliptical disk was lit up, by the consistent application of an electric shock. After the dog had thoroughly mastered these signals, the experimenter changed the shape of the ellipse slightly every few days, making it a little shorter and a little wider. The dog continued to go through his performances several times a day, never making a mistake. One day, however, when he came into the laboratory, he suddenly *went mad*: he jumped about, but made no headway



PAVLOV'S ARTIFICIAL NEUROSIS

Pavlov conditioned a dog to come whenever a certain signal appeared and to run away whenever another signal was presented. Then the elliptical go-away signal was gradually shortened and fattened. When the dog could not distinguish the two signals, he acted like a person who does not know whether he is coming or going

in any direction, turning rapidly now one way now another; he yelled and whined, and gave every indication of being very unhappy indeed. What had happened to change this well-trained dog into a raving "neurotic"?

Many people get into this state because they do not learn early enough that throughout life we simply *must* make decisions. The child must learn that he cannot have everything, that he cannot eat his cake and have it, too. A multitude of choices does not mean that we can eat several meals at once or wear four hats at once just because we can afford them. Human life is the richest life, but we should not be embarrassed by our riches.

Through experience a child can learn that he likes vanilla better than strawberry, or the other way round. It certainly is not always easy to make decisions, but we have to learn the relative worth to us of the many possibilities. No set rules will assure happiness. Sometimes we hesitate because we have to choose between something of value now and a future value. Many try to live by the rule "Eat, drink, and be merry, for tomorrow we die." It must seem silly to take chances with a future, which is necessarily uncertain,

and to postpone the enjoyment of life. A considerable fraction of those who act on this rule will survive the gay carnival to suffer privations and headaches or worse. Many outlive by many years their very capacity to enjoy anything at all.

We cannot follow our childish impulses, for they do not fit our needs and circumstances of later years. Besides, our impulses have been conditioned by experience, our thought, our sensitiveness, our affections; and there are always conflicts among them. On the other hand, we should not go mad when we are confronted by a dilemma. Unlike Pavlov's dog, human beings can learn to stop and consider, to weigh values.

Sometimes we have to weigh immediate desires against remote consequences—consequences to others as well as to ourselves. A child constantly asks, "Why must I?" or "Why mayn't I?" He does not understand possible consequences. But an older, responsible person has to make decisions that consider far-off consequences in many different directions. Eventually, mature men and women seem to adopt a style of life that does take account of consequences as a matter of course.

Whether a person who knows more and considers more and is sensitive to more is "happier" than one who does from moment to moment as he likes it is impossible to answer. We can say only that as people do become more sensitive and more understanding and more considerate, they seem also to get more out of life. Human beings are social and do not normally choose to live as "individualists" in isolation. Living in the group, we cannot carry on, however, the kind of conduct that suits the protected and irresponsible infant, or the kind that a hermit might work out for himself. It comes down to a question of what kind of group one lives in, and how satisfyingly he adjusts himself to the social world of which he is a part. How does one live in the family, among his friends, in his economic life, in the club, in the church, in the community, in his whole civilization?

In Brief

The feelings which accompany our sensations and our activities are the most "real" and immediate of all experiences.

Avoiding pain and privation and gratifying the natural impulses are the beginnings of contentment and happiness.

In addition to the basic needs we share with other animals, we need the chance to act freely, to play, to make, to create by handling materials.

Human beings are disposed to explore, to wonder, to inquire, although they are also held back by fear; men must have the chance to go after what they want, whether they ever attain it or not.

The refining of our discriminations and appreciations seems to increase our satisfactions in every type of human experience; yet the capacity to enjoy goes with the capacity to suffer.

Feelings of insecurity and anxiety interfere with activities and situations that might otherwise be very satisfying.

Through our imagination we are able to feel the satisfactions and anxieties of other people, as well as those of fantasy.

If one's goals are too easily attained, he will get relatively little out of life; if one attempts the impossible, he not only may be disappointed, but may make himself ridiculous.

Our strivings are for *values* and each of us has to learn what is of most worth to him: we sacrifice immediate satisfactions for greater ones more remote; we do many things that are in themselves uninteresting or even unpleasant, because we consider them necessary for achieving the major satisfactions.

Man is a social organism: he lives in groups and gets pleasures and satisfactions from others, as well as obstructions and irritations.

What one does "for others" he really does for himself, or for that larger self of which he feels himself a part.

We learn to consider what is in the long run of greatest worth, including the welfare of others involved in the consequences of our acts.

EXPLORATIONS AND PROJECTS

1 To see how far the physical state of an organism influences responsiveness to stimulation,

a. Compare the responses of hungry animals and well-fed animals to food or to other objects. (A single animal might be studied before and after a meal.)

b. Compare the behavior of a hungry and a well-fed animal (dog or cat) when invited to play, or when teased.

If there is an opportunity to visit a menagerie at different times, compare the behavior of caged animals in response to stimulations of various kinds before and after they are fed. Summarize observations in general statements. Supplement your own observations with examples from history, biography, and fiction, to show how human conduct appears to be modified by extremes of thirst or hunger.

2 To find out what there is in common among a variety of substitute interests, have each member of a group list what he finds most satisfying or interesting in some particular type of passive recreation, such as the movies, sport news, comic strips, poetry, and visiting an art gallery. (It is, of course, not sufficient to record merely that one "likes" or "enjoys" reading a book or seeing the movies; each should stop and ask himself just what it is that he likes or enjoys or finds satisfying in a particular

type of experience.) Find as many *common* items as possible among the different sets of "enjoyments". How do these satisfactions differ from similar satisfactions derived from *active* participation in sports, in adventure, in work, etc.? In what ways may we account for the resemblances between actual experience and substitute experience? How may we account for resemblances among the satisfactions furnished by *various types* of substitute experience?

3 To see how far variations in taste may be traced to their sources, have each member of a group list three "best liked" and three "most disliked" foods, plants, colors, animals, types of person, or other class of experience. Have each one try to account for a strong like or a strong dislike by telling either (*a*) *how* he came to have strong feeling in the case, or (*b*) *why* he considers the item desirable or undesirable, pleasing or displeasing. How far are we able to account for our preferences? To what extent are our preferences determined by good "reasons"? To what extent do our tastes seem to be influenced by the customs or usages of those among whom we have grown up?

4 To show how far human activities yield satisfactions unrelated to practical "needs", have members of a group list games or hobbies in which they are individually interested and analyze them to find out just what features appear to furnish pleasant feelings. What is common to many different games or hobbies? What appears to appeal to some individuals but not to others? What hobbies or games have been developed into careers or means of livelihood? What hobbies have developed results in the form of knowledge or devices that are socially valuable? Gather examples of hobbies that depend upon interest in living objects—collecting, classifying, comparing structure, dissecting, displaying, social statistics, painting, modeling, etc. Gather examples of hobbies that depend upon interest in living processes—migration, combat, food-getting, training animals, experimentation, breeding plants and animals, landscaping, social work, nursing, law, education, Red Cross or relief work, fishing, city-planning, etc.

5 To estimate the importance that is increasingly attached to recreation find out (*a*) what your own community has been doing over a period of years through the department of parks, through the schools, and through other public and private agencies to provide facilities for recreation; (*b*) what your state agencies have been doing; and (*c*) what is being done by the United States Department of the Interior through the national parks (obtain the Department of the Interior publication *Park and Recreation Structures*, which describes the various facilities available and offers suggestions for constructing similar appliances in local playgrounds). A committee might profitably survey recreational needs in the community and confer with representatives of other groups or organizations with a view to increasing or improving facilities.

QUESTIONS

1 How do the needs of human beings differ from those of other species?

2 In what ways is human capacity for pain and for pleasure probably different from that of other species?

3 In what ways do individuals come to prefer some experiences to others?

4 In what sense is it true that human beings make more "mistakes" than members of other species? Why is that not a handicap in the struggle for existence?

5 In what way does the fun of running or swimming differ from the fun of running or swimming in a race, and from the fun of watching a race or watching a motion picture of others in action?

6 What is there to show that painful or pleasurable feelings are possible without the direct stimulation of sensory nerves?

7 What scientific discoveries have helped to reduce mental and physical suffering associated with disease or injury?

8 In what ways do human satisfactions increase from our living in society? In what ways do they suffer from this fact?

9 How is material wealth related to happiness? How is it possible to be happy without wealth? How is it possible to have abundant wealth without being happy?

10 What are some of the obstacles to the wider use of our material and cultural resources?

11 In what sense are the things people do for fun as important as "necessary" work?

Far back in the earliest stages of man's existence, human beings must have had some sort of knowledge about life, about living things, about the human body and its workings. These ideas about plants and animals, about pain and hunger, about plagues and famines, together made up the "biology" of any particular tribe or family, of any particular period or region. These ideas guided the practices by which man lived. While other animals learn from experience, human beings appear to be the only ones that invent words and signs which enable them to carry experiences from one to another, as from parents to children. Men also invent imaginary beings to help them explain how things work. These inventions or ideas may be in the form of ghosts and goblins or in the form of natural forces or "principles". They help in many ways to carry on the needed work. But often they keep us from making the best use of experiences and resources. They may actually interfere with learning from further experience.

When ancient peoples began to keep records of their cattle and crops, their priests had already begun to write down their secret wisdom. They recorded good and evil plants and animals, correct ways of ensuring good harvests or increasing livestock, secrets about curing various sicknesses or about overcoming a drought. We should probably rate most of this lore as not very reliable, perhaps even as superstitious. At least, we cannot understand how the color of an ox used in plowing, for example, can influence the growth and ripening of the grain; or how the symbols painted over a barn-door can ensure the health of the cattle. Primitive biology often mixed religion and morals with practical rules and prohibitions; but it served.

Modern biology, as a branch of scientific study, has made rather sharp separations between *what is* and *what we wish* or *fear*. It has attempted to analyze the actual workings of all kinds of plants and animals, both in their outside relations and in the inner processes of organs and tissues. These studies furnish much more dependable understandings of our own body and the conditions essential to its healthy growth and development than we ever had in the past. As a result, we have completely revolutionized our ideas about keeping human beings well and supplying them with what they need.

By developing scientific methods of dealing with problems, we learned rather suddenly to overcome some of the oldest of the obstacles to the enjoyment of life. The causes of many sicknesses are definitely known. Promising research on the causes of others is under way. Bacteria, protozoa and viruses could not have been known in earlier periods, because they cannot be revealed without our modern instruments and techniques. As invisible but unquestionably powerful agents, they could in the past be reasonably considered as "spirits".

Epidemics that formerly wiped out from 15 to 50 per cent of a population have come under control. Several communicable diseases are no longer the leading causes of death. Not only are people generally better nourished and better able to work and play, but the life span has been substantially lengthened. We have not conquered death, but we have postponed the funerals for millions of men, women and children now living, by an average of ten years or more.

The many measurable improvements in health and the tremendous increase in usable materials of plant and animal origin are due to advances in various branches of biology. But biology does not advance by itself. Basic reasons why all sciences developed rapidly in the past century are the great expansion in popular education, a great increase in the amount of reading, and improved communications among workers of different nations. But these things are not independent happenings. They are related to one another, and they are related to the so-called industrial revolution, which made possible the rapid development of productive technology. These industrial changes set free more and more time that people could use for exploring, experimenting, thinking and research. The resulting gains in turn helped to accelerate the process.

These tremendous gains have not been universal. Large sections of the population are still undernourished, badly housed, suffering from preventable sicknesses and deficiencies, and still living in gross ignorance and superstitions and fear. Yet there is hardly a farmer who does not make use of modern science. He uses chemical knowledge about fertilizers, bacteriological knowledge about life within the soil, soil knowledge and water knowledge about plowing and cultivating. He uses genetic knowledge in deciding what types of seed to use, mycological knowledge and entomological knowledge in protecting the crops against pests. His daily work with his livestock involves a wide range of specialist knowledge regarding each particular type of animal, and again he uses the knowledge of the biochemist, the bacteriologist, the geneticist, the physiologist.

It would be absurd to pretend that each farmer is an expert in all branches of biology, as well as the other sciences. Yet his present-day performances and his achievements would not be possible without the work of hundreds of specialists. Indeed, if he could himself carry in his own head all the knowledge of these many specialists, he could not possibly use that knowledge through his own activities. That is to say, this modern farmer makes daily use of countless discoveries from laboratories scattered throughout the world; he spreads seeds, fertilizers, poisons and sprays assembled from all quarters of the earth; and he works the soil with machinery brought from widely scattered factories and made of many different metals and other materials which he could not gather by himself in a lifetime.

No one person can be "scientific" by himself. The science which we use is a social product that has involved countless workers from all over the world for generations. Using our science depends also upon thousands of widely scattered technical jobs that furnish multitudes of materials and products. These have to be distributed through commercial channels and placed finally in the hands of the individual "scientific" farmer or "consumer".

Using scientific knowledge, devices and practices for preventing sickness and for maintaining health involves similar complications and interrelations. One keeps well or gets well through public and private agencies and through professional workers—doctors, dentists, nurses, pharmacists, hygienists, bacteriologists, pathologists, radiologists, anesthetists, sanitarians, and other socialized aids and assistants.

We have abolished pain and hunger and other physical suffering—in spots. But those very qualities of human beings that have made possible all their civilization in the past have created new demands—which are not so easily satisfied. For man has enlarged his world and strengthened his control through his imagination and invention and curiosity and experimentation. It is through his language and social interactions that he has accumulated experiences from all regions and all ages to use upon particular problems. But these characteristics sensitized him also to new kinds of unhappiness.

Man seems to need symbolical, or representative, activities that assure him of his own worth and ability—and that impress others. He must satisfy these inner needs through work and play. If he cannot find forms of activity that are socially acceptable, he is likely to find modes that are socially offensive—bullying, browbeating, tricky mischief, cruelties. Various peaceful pursuits normally furnish individuals outlets for both their physical energies and their need to assert themselves and express themselves. The arts and crafts, games and specialized collecting, and numerous *making* interests should serve. But some individuals seem incapable of mastering such interests sufficiently or of finding them satisfactory. Then they find their happiness in forms that result in exploiting or abusing others. Or perhaps society has not yet succeeded in finding for all individuals civilized uses for their surplus time and energies.

The desire for *power* no doubt indicates something essential in "human nature"—whether it appears in physical conflict, in social or economic domination over others, or in military forms. To let these forms persist is to let a few attain their happiness at the expense of the multitudes. We need not seek for a change in "human nature". A solution can come only through cultivating still further equally human qualities of regard for human dignity, of sympathy and mutual aid, and through cultivating a better understanding of life, its needs, its possibilities.

IN CONCLUSION

Man the Creator

Like beavers and blue jays, human beings can put together stones and sticks and other odds and ends in their constructions. But human beings are truly creative, for they are able not only to put together what they can grasp with their hands, but also, through their thinking and imagination, to abstract, or draw out, ideas from their experiences and then recombine them into new ideas of things that never existed before. This we can see in the imaginary creations of old mythologies—gorgons, flying horses, magic carpets, evil spirits—and in the creations of artists.

Our practical work and our scientific thinking are also creative. Everybody recognizes that the remarkable progress of modern times in the solving of practical problems is connected with the growth of scientific knowledge. But it is not due to knowledge alone. The results come from combining people's purposes with the exact knowledge and big ideas of the scientists. The inventor, or the "creator" of something new, does not make something out of nothing. He combines elements of past experiences with ideas of a need to be met. Edison is said to have admitted that there was nothing in his electric lamp that had not existed before—glass bottles with air removed, copper wires, charred fibers from a plant, and so on. It was the combination that was new, and revolutionary.

The great advances in modern times have resulted in large part from inventing new devices and methods for carrying on the day's work or new gadgets for our amusement. But perhaps of greater moment has been the distribution of new understandings about the nature of the world, scientific ways of thinking, scientific ways of solving problems. A common understanding of what makes things happen has made it easier to introduce new methods of farming, for example, new methods of selecting, preserving and preparing food or new ways of preventing sickness. But it has also enabled more and more people to use scientific ways of solving their practical problems both at home and in industry, and it has greatly accelerated the process of invention. It has made it easier for people to find out what is going on in other parts of the world or what ideas and methods are being used elsewhere; and it has made it easier for people to adjust themselves to new conditions and new ideas.

In the very process of adjusting ourselves to new discoveries, new interpretations, new practices, we are breaking down old habits, old prejudices, old customs; and we are recombining elements of our own experience with

the experience of others into something new. That is creative, that makes each day almost a new day, with new possibilities that we could not have anticipated.

The most striking achievements in the creative use of biological knowledge are seen in the new species of plants and animals that have taken the place of breeds formerly cultivated. These creations are made possible by the same peculiarity of the human mind as is revealed in the other creative arts—the trick of analyzing and synthesizing. We analyze what different strains of cattle, cotton, beans, hens, tomatoes, dogs, strawberries, wheat and horses can do, what qualities they have. Then we set to work to combine useful or interesting qualities from different strains into new combinations and so produce new types of cattle, cotton, beans and so on.

This is not quite as simple as the work of the child who makes something "new" by drawing the *shape* of a pear and laying on it the *color* of a black cat. But essentially the creative process is the same. There is the analyzing of the things we observe into the different components or qualities. These elements are abstracted, or taken away, from the objects by our own thinking—the shapes, colors, dimensions, roughness, conductivity, hardness and so on. These qualities are "abstract", they do not exist by themselves; but, with our imagination and our language, we can both "think" about them and tell others about them. In a particular situation, to meet a particular need or mood, we make up a new combination of these "abstractions"—in our minds. To be able to produce something real with the new combination of qualities takes more time and more than merely thinking. But while such imagining and thinking are not sufficient, they are necessary conditions for "creating" new plants and animals.

Another creative use of biology is seen in the transformation of a cretin into a more nearly normal human being. This was made possible by analyzing certain organic processes, structures and relationships. We check on the "ideas" that go into explaining the facts by experimenting—by performing certain planned acts under controlled conditions. The test of an idea is in the answer to the question How does it work out? Later we use our knowledge to prevent the appearance of cretins. Similarly we have cured rickets and then prevented rickets. Getting rid of communicable diseases over larger and larger areas means the creating of new living conditions; but in time it may mean creating a new population.

We are now creating such a new population. Here and there in various civilized communities men and women are growing up undisturbed by the fears and anxieties that destroy the mental health of those who are ignorant and superstitious. They do not fear lightning and thunder, for they do not associate these phenomena with evil spirits or mysterious powers seeking to destroy human beings. They do not fear an eclipse of the sun, or the witches

who would poison wells. They do not fear famine, pestilence or plagues, for they rely upon the techniques which enable us to control much more effectively than ever before the operation of soils and waters, fertilizers and seeds, tractors and harvesters, as well as the means for combating insect pests and microbes. They do not fear their neighbors, for they have learned that their own welfare and their health are tied up with the health and welfare of their neighbors, and they carry on with their neighbors a constant interchange of goods and services, of ideas, sports, music and art.

Such populations are new not only in their freedom from the anxieties that cripple millions of people everywhere. They differ from the others also in their outlook on the future. By using their science in their daily work, they are able to assure to everyone the essentials of decent living. They therefore have an exceptionally broad margin of time and energy to use for activities that only human beings can carry on—just for fun. They can play. They can travel. They can explore. They can experiment. They can analyze ever new areas of human experience. And they can create.

Not everybody can make music or paint pictures or write verse that others will care about. But every healthy person can create. He can create in ways that give him satisfaction, give him the feeling that he is a person, something more than a machine, something more than an animal. He can do something distinctive—even if no more important than a parlor trick or a wisecrack, something that gets friendly recognition and approval, at least for the moment. He can make himself useful to those around him as a person, not merely as a hand.

Science Disarranges Things Some of us have no interest in science. Perhaps we are too busy with other things, or we protect ourselves against all new ideas. Yet we cannot escape what science is doing to our manner of life. The achievements of scientific research are daily brought to our attention not only through the newspapers and magazines, but through changes in the things we have to buy. There are new packages, but new ways of preparing the contents too. Our food materials come from remote corners of the earth, and we eat new preparations of what formerly had not been used. Today cotton fiber, as well as cotton oil and filterpress residue and other materials, serves us in totally new ways. At the beginning of this century, cottonseed oil was not used as human food at all. Soybeans and a dozen other crops have come to be important features of American agriculture in comparatively recent years. We raise fur-animals on farms instead of waiting for trappers and hunters to bring the pelts. And new furs that trappers never saw are being created—such as the white mink, derived from an albino mutation.

Some of the gains of science reach the ordinary person through various professional workers. Dentists and physicians change their methods. They

use new materials and new instruments. They make a diagnosis more quickly or less annoyingly. They perform their operations more expeditiously or painlessly. Nearly every trained worker, in almost every field, is constantly saying to his public, "We don't do things that way now, we do thus instead, for the scientists have found out that . . ." The service he renders may be several years more modern than his diploma, even if it is not up to the sensational statement in this morning's paper.

At the same time, we are very far from making full use of the power which our science and technology obviously make possible. Some men and women in every occupation continue to operate as they have always done. What was good enough for their fathers they consider good enough for them. They do not seem to recognize that what was good enough for their fathers was the best to be had at the time. It is no longer good enough when a large part of the population can do better. Besides, the same methods today are really not the same. Farming on virgin soil, for example, allowed a succession of good-enough crops. The same procedure on exhausted soil is the same only in carrying out the same motions. To continue old procedures when the conditions have changed is like repeating magic words and magic gestures without knowing what they mean or how they are supposed to produce their magical effects.

Obstacles to Progress There are many obstacles to making prompt use of new knowledge. Nearly every home, every farm, every industry or business establishment, has on hand equipment and supplies and materials that have been serviceable in the past. To take on a new style of living or operating would mean to make a considerable part of these assets worthless. In our daily dealings we try to make the old car or the old furniture last as long as possible. When we do have to install new equipment, we try to trade in the old for whatever it will bring. In fact, we cannot afford to scrap all the old things. From the business point of view, putting new ideas to work nearly always means scrapping old machinery and equipment, or getting new capital, or both.

Putting new scientific ideas to use often means designing new machinery, organizing plans for operating it, planning changes in distribution or selling. It means training workers. Older workers often resist such training. Many feel that if their skills were valuable in the past, they must continue to be valuable into the future. The really good craftsman, however, like the competent professional worker, has been continually adjusting himself as new ideas, new tools, new materials, came along. One of the most useful things an individual can learn is just this trick of making constant adjustment to the changes in our ways of working, as well as in our ways of living.

Each step involves its own particular difficulties and obstacles, expenses and risks. And each, of course, takes time. When the advertiser gets around

to telling you about the very latest, there must have been months, or even years, of planning and changing and getting ready.

Perhaps the chief obstacle to making fuller use of scientific discoveries and scientific ways is the attitude of the general public, which has not been educated to understand science as something that concerns everybody. Education has meant for most people, until recently, learning what's what and blocking the road to everything different—which includes everything new. The great obstacle is thus in ourselves. Most of us are willing enough to replace our old clothing or furniture with something more fashionable. But we are not so ready to replace old habits or old beliefs—or old feelings. Particularly are we afraid of anything that threatens our comfort or security. Scientific discoveries, scientific theories and new inventions come into conflict with our customary thinking, our established advantages or special privileges.

The Cost of Improvement At any given moment we may be able to figure out that a particular change would be an improvement—insulating the roof, for example, or using some new plastic in place of wood. An electric refrigerator is an improvement on the icebox. In a particular family the details can be worked out—and now you have your refrigerator. But what about the iceman? How about the man who cut and stored ice from the lakes during the winter? How about those good icehouses remaining idle or cracking up? How about the man who had been trucking sawdust to the icehouses or ice to the railway station? Those people are all very far away, and we do not have to think about them. Besides, we cannot be responsible for everybody.

Every change that is brought about by our scientific advances has far-reaching consequences—for better very often, but also for worse. The refrigerator and the internal-combustion engine and methods for fixing atmospheric nitrogen were not worked out by biologists, but they all have a direct bearing on our using biological knowledge. That is, we can apply our knowledge of plant needs to raising crops by using the chemist and the electrician to supply nitrogen for soil that lacks it. We can use tractors to ease our working of the soil. Our trucks can redistribute materials that are excessive in one area and deficient in another. Improved transportation enables us to bring our soil products to cities far from the cultivated lands. And our refrigerators enable us to keep food from spoiling for a long period.

On an average, we are making great advances. But we are becoming more and more concerned with what happens to particular men and women and to their children as a result of our advances. It is, of course, not the "improvements" that make trouble, but the dislocations or disarrangements without which we seem unable to put the improvements into effect. It has been nobody's business what happens to the iceman, or to Chile's nitrate-

diggers, or to the horse-raiser, the harness-maker, the wheelwright. It has been nobody's business if the iceman and others like him feel themselves pushed out of modern life, with all its exciting improvements.

It should not be difficult for us to understand why the iceman found natural ice superior to mechanical, or artificial, ice. Or why the harness-maker thought that it must be bad for our insides to be shaken up by the automobile. Or why the candlemaker and dealer in oil lamps suspected that electric light must be bad for the eyes. If we have used these various modern devices without harm, we may suspect that persons are biased in their judgments by their special interests.

Science Is Objective In scientific research it is necessary to guard against the fact that we are all influenced by our interests, by our earlier experiences and associations. We are all likely to form advance judgments, or *pre*-judices. Scientists therefore try very hard, in thinking of their problems, to avoid the usual human concerns and anxieties and purposes as much as possible. We say that the scientist tries to describe what *is*, no matter what the effect may be on people's likes or dislikes, their losses or profits. That is what is meant by saying that "science attempts to form judgments uninfluenced by considerations of value".

One of the unfortunate consequences of separating "value" considerations from scientific pursuits is that many grow up with the idea that there is some special virtue in disregarding human feelings and interests. That is why scientists often appear "cold", or indifferent to people's sentiments. When the scientist watches his microscopic preparations and his test tubes and his indicators, he must not let himself or his observations be influenced by what he would like the results to be. He must record unflinchingly just exactly what he finds. But it is foolish to pretend that the scientist's efforts and results are "good for their own sake".

The efforts and findings of the scientist, aside from amusing the scientist, are good only because they may help human beings ease their difficulties, solve their real problems, enrich their lives. To be sure, we must not expect the scientist to tell us day by day of what use his findings are. Some discoveries are not ready for us to use until many years after the discoverer is dead. Some cannot be used until after certain other discoveries have been made, or certain devices have been perfected. But we do have a right to ask the scientist whether he conceives his efforts to be of human value, or of interest to himself alone. We have a right to ask this because the scientist's work is really paid for by all of us, and it is made possible by the accumulations of learnings and ideas from the past. These inheritances from the past belong, of course, equally to all of us; but the scientist is the person who has had the opportunity to master a part of this heritage and is in a position to manage it. He manages it, however, as society's custodian.

There is another question that is becoming more and more urgent for us to answer in connection with science. Since science grows in a special social medium, which furnishes the opportunities and the heritage from the past, and since making use of science depends upon very complex organization and wide co-operation, we shall have to answer the question Who owns science? Is it the individual investigator making a particular discovery? Is it the university or other laboratory in which he works? Is it the individual or corporation that hires the scientist, often using his results for private gain rather than general advantage?

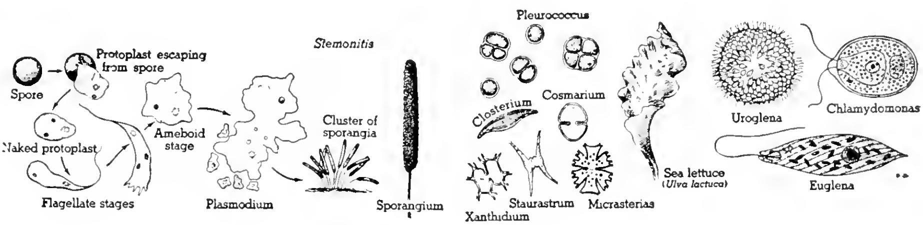
Man's adjustments to life depend more and more upon his imagination and intelligence and invention. They depend more and more upon the division of labor, co-operation on a larger and larger scale, and more socialization of effort. Science cannot continue to serve us unless we give it a chance to serve the whole community, the entire race. For if we do not use it creatively to serve all, but let it be turned aside for private or partial interests, we shall convert the power which science yields into the most destructive that man has yet tried to control. Any individual or any group that seeks to control science becomes the enemy of all mankind.

APPENDIX A

Grouping of Plants and Animals

We separate all the forms of living things we know into "plants" and "animals" without any effort. All except a very few of the plant species have chlorophyl, and all but a few remain in a fixed place. All the others we call animals, although there are many species of animals that do not roam about. Some natural objects, however, are unmistakably "living" and yet are not so easily classed as plants *or* animals. We have seen that a "virus" resembles a chemical compound rather than a complex living structure (see page 444); and yet a virus increases in quantity at the expense of suitable "food", just as growing protoplasm does.

Other living forms that lie between plants and animals are the so-called "slime molds", or *Myxomycetes*, which are sometimes classified as true fungi. In the active, or vegetative, state the organism consists of a large mass of naked protoplasm containing numerous nuclei. This mass moves about in an ameboid fashion, and is negatively phototropic. When exposed to drying or to light, it develops rather complex spore-bearing structures, resembling some of the molds.

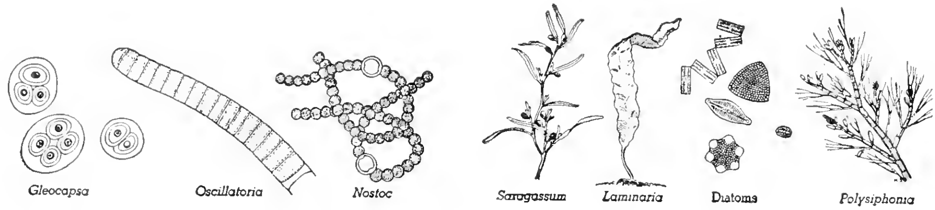


Euglena is an example of a group of one-celled chlorophyl-bearing organisms that are sometimes classed with the green algae (see illustration, below). But these species have distinct "animal" traits. In the whiplike flagellum, or swimming lash, the organism resembles the flagellate protozoa. In its method of swallowing food, it resembles the ameba. Yet it is useful and convenient to think of living species in these two main divisions—plants and animals.

Most of the names used in classifying plants and animals are Latin or Latin in form. In these outlines all Latin names have been anglicized to facilitate their pronunciation except where the Latin form is as easy or as familiar.

The outlines are, of course, not complete. The subdivisions have been carried only as far as students are likely to need them. Groups which are of little interest to any except the professional taxonomist have been either treated by a special note or omitted entirely.

The successive subdivisions in the plant-and-animal classification scheme are shown on pages 40 and 41; the "relatedness" of the various branches is shown in the frontispiece.



A. MAIN GROUPS OF PLANTS

The chief groups of plants are indicated in the following outline. As one becomes acquainted with more plants, it becomes necessary to use a more complete classification.

PHYLUM I THALLOPHYTES ("bud or shoot plants"). Plants showing no differentiation into true stem and leaf; include the smallest as well as the largest plants in the world. The thallophytes have little in common except the *absence* of distinct roots, stems, and leaves. All thallophytes, except the Class schizophytes, reproduce sexually, that is by the fusion of protoplasm from two sources. The schizophytes reproduce only by the simple division of protoplasm into two masses. The presence or absence of chlorophyl distinguishes the two divisions of the schizophytes; and it distinguishes the other two Classes of thallophytes—the algae and the fungi.

CLASS 1 SCHIZOPHYTES ("splitting plants"). Each cell splits into two; no other mode of reproduction.

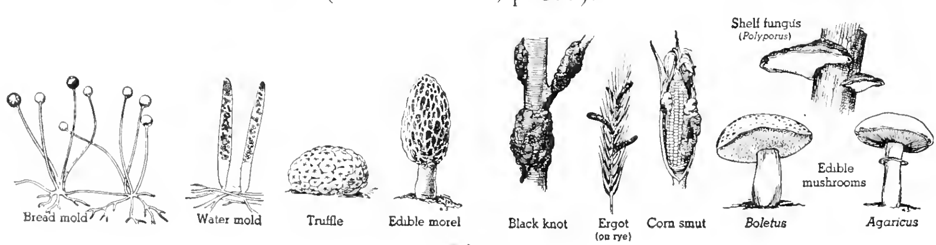
ORDER 1 CYANOPHYCEAE ("blue seaweed"). Splitting plants with chlorophyl—the "blue-green algae". *Examples,* Oscillatoria, Rivularia, Nostoc.

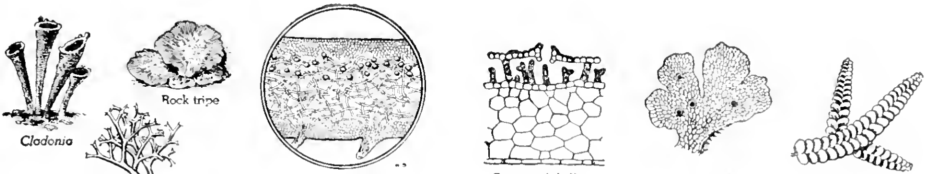
ORDER 2 SCHIZOMYCETES ("splitting fungus"). Splitting plants without chlorophyl—the bacteria (see illustration, p. 613).

CLASS 2 ALGAE ("seaweeds"). The chlorophyl-bearing thallophytes; all live in water or in moist places.

ORDER 1 CHLOROPHYCEAE ("green seaweed"). The green algae; usually yellowish green. *Examples,* pleurococcus, desmids, stonewort, sea lettuce, spirogyra (see illustration, p. 375).

ORDER 2 PHAEOPHYCEAE ("dusky seaweed"). The brown algae; mostly marine. *Examples,* Laminaria Sargassum, giant kelp, sea palm, bladder wrack (see illustration, p. 377).





Cladonia — Rock tripe — Reindeer moss — Cross section of lichen thallus — Section of thallus — *Marchantia* (over-all view) — *Porella*

ORDER 3 RHODOPHYCEAE ("rose seaweed"). The red algae; mostly marine; attached to rocks; reddish to purple. *Examples*, *Nemalion*, or threadweed, *Polysiphonia*, *Batrachospermum*.

CLASS 3 FUNGI ("mushrooms"). Thallophytes without chlorophyl.

ORDER 1 PHYCOMYCETES ("alga fungus"). Algalike fungi; no divisions in hyphae. *Examples*, water molds (often parasitic on fishes), *Phytophthora* (the cause of potato rot), downy mildew, black or bread mold (see illustration, p. 375).

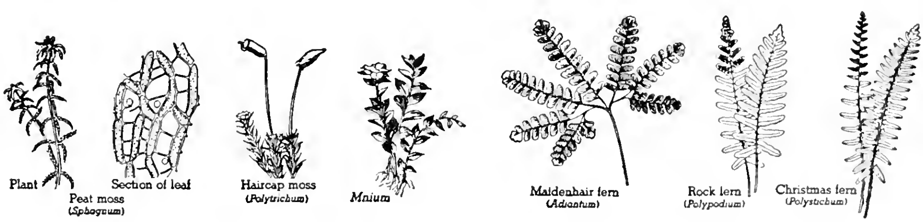
ORDER 2 ASCOMYCETES ("bladder fungus"). Fungi bearing spores in sacs; hyphae divided into cells. *Examples*, cup fungi, the edible morel, the mildews, black knot, yeast (see illustration, p. 371).

ORDER 3 BASIDIOMYCETES ("basidium fungus"). Fungi bearing spores on outside of a steplike structure called a basidium, from basis, or pedestal. *Examples*, rusts, smuts, mushrooms, pore fungi, shelf fungi, puffballs (see illustration, p. 594).

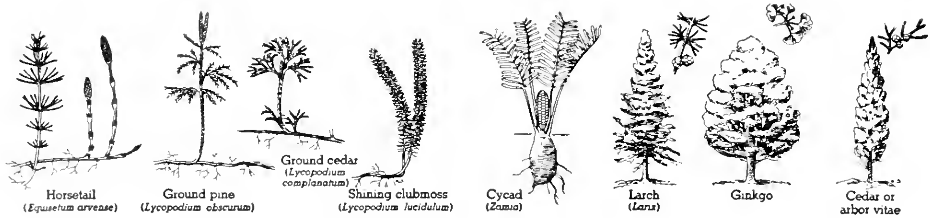
GROUP 4 LICHENS These curious structures are compound growths of fungi and algae. The fungal partner is generally an ascomycete; the algal partner is a green alga related to pleurococcus or to one of the blue-green algae. *Examples*, rock tripe, reindeer moss, Iceland moss, Spanish moss.

PHYLUM II BRYOPHYTES ("moss plants"). Mosses and their allies. This phylum of plants shows several advances over the algae and fungi. There is a well-marked sexual reproduction with archegonia and antheridia, as well as definite formation of spores; all have a regular alternation of sexual and asexual generations. There is no vascular system, that is, no specialized conducting tissue in the supporting structures.

CLASS 1 HEPATICAE ("liver"). Liverworts; body consists of flat, leaflike, green, forking thallus; live in moist places. *Examples*, Marchantia, Riccia.



Plant — Section of leaf — Peat moss (*Sphagnum*) — Haircap moss (*Polytrichum*) — *Mnium* — Maidenhair fern (*Adiantum*) — Rock fern (*Polypodium*) — Christmas fern (*Polystichum*)



CLASS 2 MUSCI ("moss"). Mosses; small erect or trailing plants with a beginning of differentiation into stalk, leaflike outgrowths, and rootlike hairs; spores borne in capsule, at end of hairlike bristle. *Examples*, sphagnum, or peat, moss, hair-cap moss, fern-leaf moss, pin-cushion moss, pigeon-wheat moss.

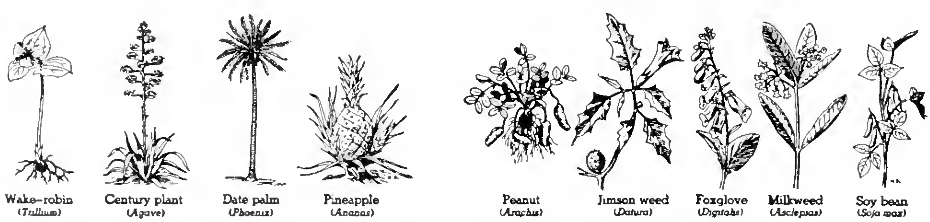
PHYLUM III PTERIDOPHYTES ("fern plant"). Ferns and their allies; have distinct leaves, stems, and roots with vascular system; archegonia and antheridia present in prothallus, or sexual, generation; spore-bearing asexual generation grows into trees in some species.

CLASS 1 FILICALES ("fern"). The ferns; have large pinnately veined leaves called *fronds*; young fronds uncoil from buds and suggest "croziers"; roots and stems anchored in soil; sporangia in characteristic clusters called sori (see illustration, p. 387). *Examples*, polypody fern, Christmas fern, cinnamon fern, bracken fern, sensitive fern, tree ferns.

CLASS 2 EQUISETALES ("horse bristle"). The horsetails; erect, fluted, jointed, green stems grow from horizontal underground stems; leaves cluster around vertical stems, suggesting shape of horse's tail; sporangia borne in conical structure at tip of stems. *Examples*, scouring rushes, horsetails.

CLASS 3 LYCOPODIALES ("wolf foot"). The club mosses. Small evergreen plants usually found in moist woods; sporangia in club-shaped cones. *Examples*, ground cedar, ground pine, shiny club moss, ground cypress, selaginella.

PHYLUM IV SPERMATOPHYTES ("seed plants"). Seed-bearing plants; produce true seeds which arise from fertilized eggs, and also spores. There is a true alternation of generations, as in the mosses and ferns; but that is not so easily observed, since the egg-and-sperm, or sexual, generation can be studied only with the use of microscopes and difficult preparation of materials. As in the case of the ferns, the familiar generation is the spore-bearing one. The pollen corresponds to spores (see illustrations, pp. 12, 31, 412, 399–408, 410).



CLASS 1 GYMNOSPERMS ("naked seed"). Naked-seed plants; include all the cone-bearing trees. *Examples*, cycads, ginkgo, sago palm, yews, larches, pines, cypress, spruces, cedars, sequoias.

CLASS 2 ANGIOSPERMS ("enclosed seed"). Enclosed-seed plants; most of the familiar plants belong to this class; includes the broad-leaved trees, shrubs, grasses, herbs, vegetables, fruits, and farm crops.

SUBCLASS 1 MONOCOTYLEDONS With one cotyledon; bundles scattered throughout the stem; parallel-veined leaves; flower parts usually in 3's or 6's. *Examples*, cat-tail, water plantain, grasses and grains, sedges, palms, Indian turnip, rushes, spiderwort, lilies, bananas, orchids (see illustration, p. 146).

SUBCLASS 2 DICOTYLEDONS With two cotyledons; woody bundles arranged symmetrically in stem; net-veined leaves; flower parts usually in 4's or 5's (see illustration, p. 147).

ORDER 1 ARCHICHLAMYDEAE ("primitive coat, or envelope"). Petals in flowers either quite separate or entirely lacking. *Examples*, catkin-bearing trees (willows, walnuts, oaks, beeches), smartweed, pink family, buttercup family, water lilies, rose family, parsley family, bean family.

ORDER 2 SYMPETALAE ("joined petals"). Petals united into tube or cup. *Examples*, heath family, primrose family, gentian family, mint family, morning-glory family, plantain family, madder family, honeysuckle family, composites (daisy, aster, sunflower, goldenrod, etc.).

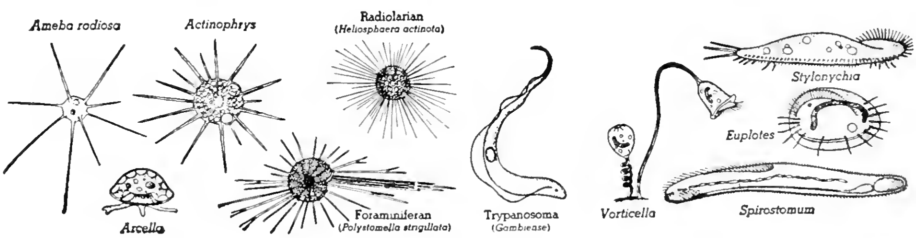
B. MAIN GROUPS OF ANIMALS

The main branches of animals and the subdivisions of the more important branches are outlined below.

PHYLUM I PROTOZOA ("first animals"). The simplest animals; body of one cell; live for the most part in fresh or in sea water, but many species are parasitic in plants and animals.

CLASS 1 SARCODINA ("flesh"). Body without definite shape; move by means of false feet, or pseudopods (see illustrations, pp. 23 and 25).

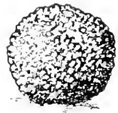
CLASS 2 MASTIGOPHORA ("whip-bearing"). Body of definite shape enclosed in cuticle; move by means of one or more whiplike flagella (see illustration, p. 179).



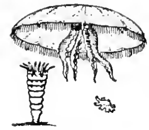

Grantia ciliata


Euplectella


Chalina oculata


Euspongia officinalis


Coral (*Corallium rubrum*)


Jellyfish (*Aurelia aurita*)


Sea walnut (*Pleurobrachia pileus*)

CLASS 3 INFUSORIA ("poured into"). Move and feed by vibrating hair-line projections called cilia, which extend through the tough outer covering; abound in hay-infusions.

CLASS 4 SPOROZOA ("spore animals"). Parasite forms; produce spores at some stage in the life cycle; malaria fever, Texas cattle fever, and the silk-worm disease pébrine are caused by representatives of this group (see illustrations, p. 622).

PHYLUM II PORIFERA ("pore-bearing"). Consist of innumerable similar cells supported on a porous calcareous, siliceous, or horny skeleton; mostly marine.

PHYLUM III COELENTERATES ("hollow intestine"). Radially symmetrical animals having a single cavity in the body; all aquatic, mostly marine; many have a marked alternation of generations in their life cycle.

CLASS 1 HYDROZOA ("water animal"). *Examples*, fresh-water hydra, certain small jellyfish (see illustrations, pp. 274 and 384).

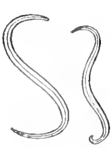
CLASS 2 ANTHOZOA ("flower animal"). *Examples*, most sea-anemones, most corals (see illustration, p. 92).

CLASS 3 SCYPHOZOA ("cup animals"). *Examples*, most of the larger jellyfish.

CLASS 4 CTENOPHORE (ten′ofor, "comb-bearer"). *Examples*, comb jellies and sea walnuts. The ctenophores differ from the coelenterates in many essentials and are sometimes classed as a separate phylum.

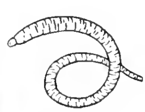
PHYLUM IV FLATWORMS (Platyhelminthes, "flat worms"). Ribbonlike soft-bodied animals without skeleton; many are parasitic. *Examples*, tapeworm, liver fluke, planarians (see illustrations, pp. 615 and 229).

PHYLUM V ROUNDWORMS (Nemathelminthes, "thread worms"). Small cylindrical, soft-bodied animals without skeleton, unsegmented, both parasitic and free-living forms (see illustration, p. 615). *Examples*, hookworm, trichina, ascaris, thorn-headed worm.


Ascaris


Necator americanus

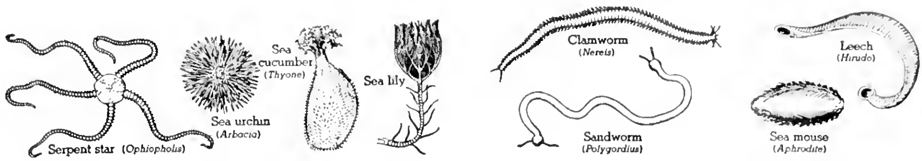

Trichinella


Anthocephala


Rotifer (*Philodina*)


Case building rotifer (*Floscularia*)


Glass worm (*Sagitta*)



PHYLUM VI WHEELWORMS (Trochelminthes, "wheel worms"). Minute "worms" with front end of body ciliated and hind end usually forked; the beating cilia on the rotifers give impression of one or more revolving wheels; abound in stagnant water.

PHYLUM VII ECHINODERMS ("spiny-skinned"). Radially symmetrical marine animals; usually with calcareous spines in skin and with well-developed water-tube system (see illustration, p. 230).

CLASS 1 ASTEROIDS. Starfish.

CLASS 2 OPHIUROIDS. Brittle stars.

CLASS 3 ECHINOIDS. Sea urchins.

CLASS 4 HOLOTHUROIDS. Sea cucumbers.

CLASS 5 CRINOIDS. Sea lilies.

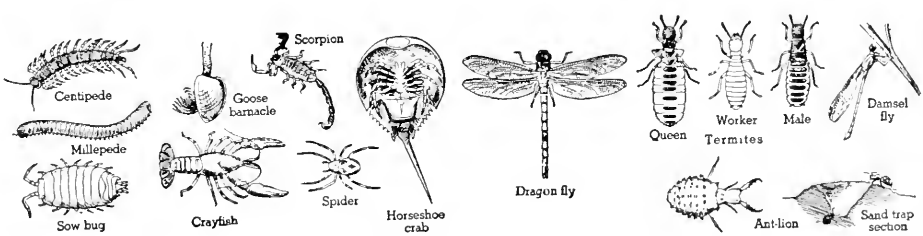
PHYLUM VIII ANNELIDS ("ringed"). Cylindrical worms with segmented bodies; red blood in a closed circulatory system; comparatively highly developed nervous and sensory system. The two most important classes are represented by earthworms and sandworms, which have bristles, or setae; and leeches, which are without bristles and have a sucker at each end.

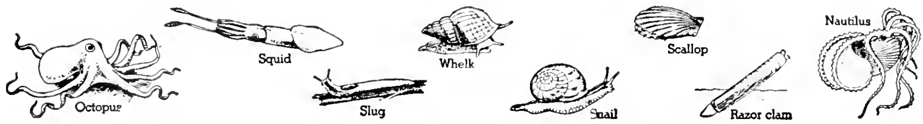
PHYLUM IX ARTHROPODS ("jointed legs"). Have jointed limbs, a hard outer covering, the exoskeleton, and segmented bodies; jaws work sidewise.

CLASS 1 MYRIAPODS ("thousand legs"). The millepedes, with inconspicuous antennae and two pairs of legs on each segment; and the centipedes, with conspicuous antennae and one pair of legs on each segment.

CLASS 2 CRUSTACEANS ("crusty shells"). Head and thorax fused into a cephalothorax; five or more pairs of legs; water-breathers; antennae. *Examples*, crayfish, crab, shrimp, barnacle, sow-bug, lobster (see illustrations, pp. 173, 359, 391, 420 and 461).

CLASS 3 ARACHNIDS (spiders, "spinners"). Four pairs of legs; air-breathers; no antennae; a cephalothorax. (The horse-shoe crab is an excep-





tion in that it is a water-breather and has six pairs of legs.) *Examples*, scorpions, spiders, daddy longlegs, tarantula, mites, ticks (see illustrations, pp. 617 and 561).

CLASS 4 INSECTS ("cut in"). Body segmented; three distinct parts—head, thorax, and abdomen; three pairs of legs; usually two pairs of wings; antennae; compound eyes; breathe air through numerous branching tubes called tracheae; metamorphosis of some forms includes egg, larva, pupa, and adult stages (see illustrations, pp. 352, 353 and 655). This important class comprises more than half the animal species. The chief orders are as follows:

ORDER 1 DIPTERA ("two-wings"). Hind pair of wings reduced to tiny knobs, or balancers; complete metamorphosis; sucking or piercing mouth. *Examples*, mosquitoes (see illustration, p. 623), gnats, midges, houseflies, stable flies, botflies, warbles, fruit flies (see illustrations, pp. 489, 490, and 513).

ORDER 2 LEPIDOPTERA ("scale-wings"). Rigid membranous wings covered with minute scales; complete metamorphosis; sucking proboscis. *Examples*, all butterflies and moths (see illustrations, pp. 180, 263, 353, 391 and 655).

ORDER 3 HYMENOPTERA ("membrane-wings"). Complete metamorphosis; biting or sucking mouth. *Examples*, wasps, hornets, bees, ichneumons, ants (see illustrations, pp. 352 and 410).

ORDER 4 COLEOPTERA ("sheath-wings"). The front wing a hard protective cover; complete metamorphosis; mostly with biting mouth. *Examples*, beetles, weevils, fireflies, ladybird, June-bug (see illustrations, pp. 352, 596 and 655).

ORDER 5 HETEROPTERA ("unlike-wings"). Front pair of wings usually leathery at base and membranous near tip; incomplete metamorphosis; sucking mouths. *Examples*, all true bugs, squash-bug, water-bug, bed-bug.

ORDER 6 HOMOPTERA ("like-wings"). Usually have two pairs of wings with front pair uniform in texture throughout; incomplete metamorphosis; sucking mouths. *Examples*, cicadas, plant lice, scales, hoppers, white flies.

ORDER 7 ORTHOPTERA ("straight-wings"). Wings lying parallel with body or folding lengthwise; incomplete metamorphosis; biting mouth. *Examples*, locusts, crickets, walking sticks, katydids, cockroaches, mantis.

ORDER 8 ODONATA ("toothed"). Four elongate, net-veined wings, almost exactly alike; incomplete metamorphosis; large biting mouth. *Examples*, dragon flies, damsel flies.

ORDER 9 ISOPTERA ("equal-winged"). Four leathery wings of equal width; incomplete metamorphosis; biting mouth; whitish body. *Example*, termites (see illustration, p. 179).

ORDER 10 NEUROPTERA ("net wings"). Four elongate wings with cross-veins; complete metamorphosis; biting mouth. *Examples*, ant-lions, aphis-lions.

ORDER 11 SUCTORIA ("sucking"). No wings; complete metamorphosis; sucking mouth; body flattened from side to side; hind legs fitted for jumping. *Example*, fleas.

ORDER 12 SIPHUNCULATA ("tube"). No wings; incomplete metamorphosis; sucking mouth; body flattened from top to bottom. *Examples*, lice, cooties.

PHYLUM X MOLLUSKS ("soft"). Unsegmented, soft-bodied animals, most of them bearing shells. The most important classes are

CLASS 1 GASTROPODS ("belly-footed"). Having shells of a single piece.

CLASS 2 PELECYPODS ("hatchet-footed"). Bivalve, that is, shells have two valves. *Examples*, oysters, piddocks, scallops, mussels, shipworms, clams (see illustrations, pp. 32 and 209).

CLASS 3 CEPHALOPODS ("head-footed"). The foot partly surrounds the head and has a number of arms, or tentacles. *Examples*, octopus, cuttlefish, squid, nautilus.

PHYLUM XI CHORDATES ("cord"). Animals having an internal axial basis for a skeleton, called a *notochord*, from which the vertebral column develops. A number of small animals have this structure, which suggests the beginning of such a column, but never develop a true backbone. *Examples*, acorn worm, lancelet, sea squirt. These animals are included among the chordates in subphyla distinct from the vertebrates. All the common large animals are vertebrates.

SUBPHYLUM VERTEBRATES ("joint" or "turning"). Includes all animals with segmented backbone. The five important classes are as follows:

CLASS 1 PISCES ("fish"). Fishes are aquatic, cold-blooded animals; they have a two-chambered heart. The stone hag and the lamprey are sometimes called fishes, though they are distinct in having sucking mouths, no jaws, no side fins, and a smooth skin without scales. They never develop bones; the skeleton is of cartilage.

ORDER 1 ELASMOBRANCHS Cartilage skeleton; platelike gills; no gill covers; no air bladder. *Examples*, skates, rays, sharks.

ORDER 2 GANOIDS Armored fishes; large bony scales in skin, especially around the head; have gill covers and air bladders. *Examples*, sturgeon and gar pike (see illustration, p. 457).

ORDER 3 TELEOSTS Bony fishes; have scales in skin; air bladder. *Examples*, salmon, herring, perch, cod, flounder (see illustrations, pp. 173, 210 and 421).

ORDER 4 DIPNOI ("double breathers"). Fishes with lunglike structures, as well as gills; certain species skip over mud flats when tide is out; others burrow in mud and live through the hot dry season in a mucus-lined cocoon. Found only in the Southern Hemisphere.

CLASS 2 AMPHIBIANS ("double life"). Breathe by means of gills in early stages, familiar to us as tadpoles, and later develop lungs; have bony skeleton with two pairs of appendages and a three-chambered heart; cold-blooded; skin is without scales. *Examples*, frog, toad, newt, salamander, mud puppy (see illustrations, pp. 211, 309, 355, 379 and 421).

CLASS 3 REPTILES ("crawl"). Wholly air-breathers; dry scaly skin; four-chambered heart; cold-blooded; eggs large, with a membranous covering. Four orders are usually recognized:

ORDER 1 CHELONIA Protective shell composed of bony plates covered with horny plates; toothless jaws. *Examples*, turtles and tortoises.

ORDER 2 SERPENTS Reptiles without legs. *Examples*, snakes, adders, cobras (see illustrations, pp. 4 and 422).

ORDER 3 LACERTILIA Body and tail usually long and slender, with four legs. *Examples*, lizards, chameleons, horned toad, Gila monster, glass snake (see illustration, p. 230).

ORDER 4 CROCODILIA Large, semiaquatic, four-legged animals; though air-breathers, can remain under water for five or six hours without drowning. *Examples*, alligators, crocodiles, caymans, gavials.

CLASS 4 AVES ("birds"). Warm-blooded; four-chambered heart; covering of feathers; front limbs are wings; air spaces in bones; no diaphragm; eggs have limy shells; horny beak, no teeth.

Living species of birds can be conveniently divided into the *running*, or flightless, birds (ostrich, cassowary, emu) and the *flying* birds. In this classification the more important orders of flying birds have been grouped, so far as possible, according to their habitats, since the shapes of the limbs and beak are so distinctly associated with the mode of life. Some of the more important orders of the flying birds are listed below, with examples of typical families (see illustrations, pp. 30, 178, 293, 362, 392 and 649).

ORDER 1 Divers. Loon family, grebe family.

ORDER 2 Tube-nosed swimmers. Shearwater and petrel family, storm-petrel family.

ORDER 3 Pelican tribe. Tropic-bird family, pelican family, gannet and booby family, cormorant family.

ORDER 4 Storklike birds. Heron and bittern family, stork and wood-ibis family, ibis and spoonbill family, flamingo family.

ORDER 5 ANSERIFORMES ("goose-like"). Swan, goose, and duck family.

ORDER 6 Cranes. Wading marsh-dwellers. Crane family, limpkin family, rail family.

ORDER 7 Shore-birds tribe. Gull and tern family, plover and turnstone family, woodcock, snipe, and sandpiper family, auk and puffin family, skinner family.

ORDER 8 Falcon tribe. Diurnal birds of prey. Vulture family, kite, hawk, and eagle family, falcon family.

ORDER 9 Owl tribe. Nocturnal birds of prey. Typical owl family, barn-owl family.

ORDER 10 GALLIFORMES ("hen-like"). Hen family, grouse and ptarmigan family, partridge and quail family, pheasant family, turkey family.

ORDER 11 COLUMBIFORMES ("pigeon-like"). Pigeon and dove family.

ORDER 12 PSITTACIFORMES ("parrot-like"). Parrot, parakeet, and macaw family.

ORDER 13 CUCULIFORMES ("cuckoo-like"). Cuckoo, road-runner, and anis family.

ORDER 14 CAPRIMULGIFORMES ("goatsucker-like"). Goatsucker family —nighthawks, whippoorwills, etc.

ORDER 15 Hummingbird tribe. Swift family, hummingbird family.

ORDER 16 Kingfisher tribe. Kingfisher family.

ORDER 17 PICIFORMES ("woodpecker-like"). Woodpecker family, which includes flickers and sapsuckers.

ORDER 18 PASSERIFORMES ("sparrow-like"). Perching birds; includes most of our common birds. Lark family, swallow family, jag, magpie and crow family, titmouse and bush-tit family, nuthatch family, creeper family, wren family, mockingbird and thrasher family (see illustration, p. 424), thrush and bluebird family, warbler and kinglet family, wagtail and pipit family, waxwing family, shrike family, starling family, vireo family, wood-warbler family, weaver-finch and sparrow family, European tree sparrow, meadowlark and blackbird family, tanager family, grosbeak, finch and bunting family.

CLASS 5 MAMMALS ("breast"). Suckle young; hairy covering; four-chambered heart; warm-blooded; diaphragm. Except in the orders marsupials and monotremes, the embryos receive nourishment from the blood of the mother through a *placenta*, which becomes embedded in the uterus wall of the mother, and the young reach an advanced stage of development before birth (see page 423).

SUBCLASS and ORDER 1 MONOTREMES Egg-laying mammals; eggs hatch outside the body. *Examples*, duckbill, spiny anteater.

SUBCLASS and ORDER 2 MARSUPIALS Pouched mammals without placenta; eggs develop within the body of the mother, but young are born in a very immature state, and continue to develop within a pouch on the mother's abdomen, where they attach themselves to her teats. *Examples*, kangaroos, wombats, opossums, koalas, Tasmanian wolves, Tasmanian devils, wallabies, bandicoots, pouched rats, pouched mice (see illustrations, pp. 426 and 549).

SUBCLASS Placental mammals Conveniently classified according to the hard tissues at the ends of the "fingers" and "toes."

ORDER 3 EDENTATES ("toothless"). Clawed feet. *Examples*, sloths, armadillos, hairy anteaters, scaly anteaters, aardvarks.

ORDER 4 CHIROPTERA ("hand-wings"). Clawed feet. *Example*, bats.

ORDER 5 INSECTIVORES ("insect-eating"). Clawed feet. *Examples*, flying lemurs, moles, shrews, hedgehogs.

ORDER 6 RODENTS ("gnawing"). Clawed feet. *Examples*, rats, mice, hares, rabbits, pikas, squirrels, chipmunks, gophers, woodchucks, prairie dogs, muskrats, beavers, capybaras, cavies, porcupines.

ORDER 7 CARNIVORES ("flesh-eating"). Clawed feet. Several distinct and widely distributed families (see illustrations, pp. 463 and 548).

Dog family. Wolves, coyotes, foxes.
Hyena family.
Cat family. Lions, tigers, leopards, cheetahs, jaguars, ocelots, pumas, bobcats, domestic cats.
Mongoose family.
Bear family. Black bear, grizzly bear, polar bear.
Marten family. Otters, minks, weasels, ferrets, wolverines, skunks, badgers.
Raccoon family. Coatis, kinkajous, pandas (see illustration, p. 425).
Sea-lion family. Sea lions, fur seals.
Walrus family.
Seal family. Ringed seal, harbor seal, elephant seal.

ORDER 8 ARTIODACTYLS ("even-toed"). Hoofed feet.

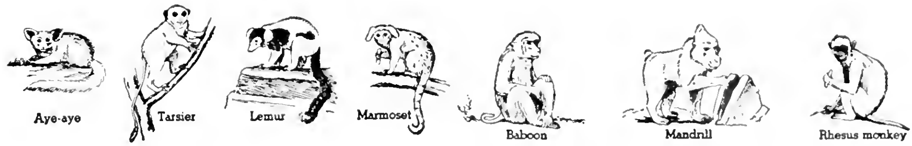
SUBORDER SUINA ("pigs"). *Examples*, hippopotamus, swine, peccaries.

SUBORDER RUMINANTS ("cud-chewers"). See illustration, p. 174.

Camel family. Camels, llamas.
Deer family. Moose, elk, caribou, antelopes, waterbucks, gazelles.
Giraffe family. Giraffes, okapis.
Oxen family. Gnus, goats, sheep, cattle, musk oxen, water buffaloes, yaks, bison (see illustrations, pp. 7, 78, 588 and 651).

ORDER 9 PERISSODACTYLS ("odd-toed"). Hoofed feet. *Examples*, horses, asses, zebras, tapirs, rhinoceroses.

ORDER 10 PROBOSCIDIANS ("with proboscis"). Hoofed feet. *Example*, elephants.



ORDER 11 SIRENIA ("siren"). Aquatic mammals with flippers. *Examples,* sea-cow, manatee, dugong.

ORDER 12 CETACEA ("whale"). Aquatic mammals with flippers.

Whalebone, or baleen, whale family. Whalebone whales, right whales, gray whales, humpback whales, rorquals.

Toothed-whale family. Sperm whales, beaked whales, killer whales, white whales, narwhals, dolphins, porpoises.

ORDER 13 PRIMATES ("first"). The leading order of animals, including man; flat nails at ends of digits, usually five on both hands and feet; thumb and great toe usually opposable.

SUBORDER LEMUROIDS ("lemur-like"). Small furry animals; some digits have nails, other claws; doglike snout. Aye-aye family, tarsier family, lemur family.

SUBORDER ANTHROPOIDS ("man-like"). Nails on all digits with exception of the marmosets, which resemble man in face only.

Marmoset family.

New World monkeys. Nearly all have long grasping tails and flat noses; thumb not opposable except in capuchin monkey. *Examples,* howling monkeys, squirrel monkeys, spider monkeys, capuchin monkeys, owl monkeys, titis monkeys, woolly monkeys.

Old World monkeys. Tail not grasping; narrow nose with nostrils pointed downward; bony external ear; thumb opposable. *Examples,* baboons, mandrills, macaques.

Simians (apes). Large, no distinct tail, thumb opposable, narrow nose, bony external ear, arms longer than legs; have an appendix.

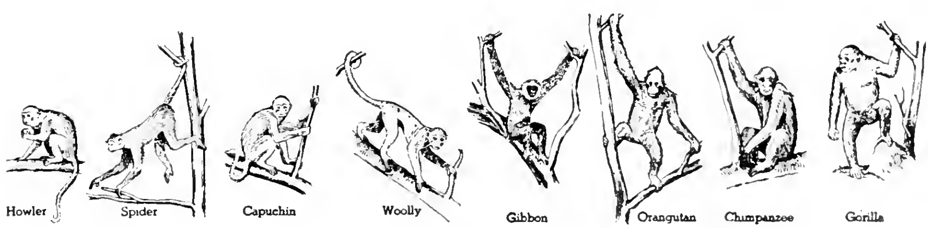
Gibbons. Long arms and legs; smallest of apes.

Orangutans. Long arms, small flat ears.

Chimpanzees. Large ears, short stout body, intelligent.

Gorillas. Small ears, largest of apes.

Humans. The human race (see illustrations, pp. 47, 52 and 517).



APPENDIX B

Supplementary Readings

When using encyclopedias or other general reference books or textbooks, it is helpful in each case to locate the parts that are of special interest by means of the table of contents or of the index. For each unit of this text, several special books are listed in the pages following. In addition, some of the more general sources of interesting reading matter are suggested. Most of the items are listed under their authors' names, which are arranged alphabetically; the most important book for a particular reader may appear at the very end of the list. Many of the books are not too specialized, and contain material of interest in connection with topics in two or more units. Each book is listed only once, however; and it is hoped that the reader will discover the resources of each book for later use.

Each agricultural experiment station and the extension division of each state university or college of agriculture in the several states publish useful bulletins and pamphlets.

The United States Department of Agriculture will send lists of Farmers Bulletins and other biological publications.

The Superintendent of Documents, Government Printing Office, Washington, D.C., issues free lists of government pamphlets on forestry, plants, health, children, birds, wild animals, food and other subjects.

College textbooks on agriculture, biology, botany, hygiene, physiology, zoology and so on make useful reference books.

Yearbooks of the Department of Agriculture and the annual reports of the Smithsonian Institution can usually be obtained through the Congressman.

Books on natural history, exploration, geography and biography often contain material that is interesting to the student of biology.

BUCHSBAUM, RALPH. *Animals without Backbones.* University of Chicago Press, 1938. [Splendid illustrations, mostly from photographs, with reliable and not difficult reading.]

CARLSON, ANTON J., and JOHNSON, VICTOR. *The Machinery of the Body.* University of Chicago Press, 1941. [Well-told and well-arranged accounts of the parts of the body and their workings.]

DARWIN, CHARLES. *Voyage of the Beagle.* Macmillan, 1933. [Surprisingly interesting look around the world by a young man who turned out to be a great scientist at heart.]

HOGBEN, LANCELOT. *Science for the Citizen.* Knopf, 1938. [A very modern and very large, but also very exciting book; to be taken in small doses.]

SNYDER, EMILY EVELETH. *Biology in the Making.* McGraw-Hill, 1940. [An easy introduction to the men who made biology, how they tackled their problems—and why.]

Wells, H. G., Huxley, Julian S., and Wells, G. P. *Science of Life.* Doubleday, 1934. [An excellent organization of interesting and informative material about all aspects of life; best used as a reference book with the help of the index.]

UNIT ONE · WHAT IS LIFE?

Collingwood, G. H. *Knowing Your Trees.* American Forestry Association, 1941. [Illustrated from photographs of the flowers, fruits, leaves and bark of trees, as well as entire trees.]

Fasten, Nathan. *Introduction to General Zoology.* Ginn and Company, 1941. [This college textbook can serve as a stimulating survey of the forms and problems of animal life.]

Hegner, Robert. *Parade of the Animal Kingdom.* Macmillan, 1935. [Good pictures and interesting natural-history accounts by a distinguished biologist.]

Jaques, H. E. *How to Know the Insects.* Published by the author, Mount Pleasant, Iowa. [Convenient key to common orders and families, with practical help for collecting and mounting.]

Peterson, Roger Tory. *A Junior Book of Birds.* Houghton, 1941. [A good introduction to the more common forms.]

Pool, Raymond J. *Basic Course in Botany.* Ginn and Company, 1940. [While intended for college students, this book contains interesting information about plants, especially as they take part in the transformation of matter upon the earth.]

Romer, Alfred S. *Man and the Vertebrates.* University of Chicago Press, 1939. [Helpful survey of backboned animals; good illustrations.]

UNIT TWO · UNDER WHAT CONDITIONS CAN WE LIVE?

Dahlgren, B. E. *The Story of Food Plants.* Field Museum, Chicago, 1940. [A good survey of the plants that man has used in various parts of the world to advance his own life.]

Furnas, C. C., and Furnas, S. M. *Man, Bread and Destiny.* Reynal & Hitchcock, 1937. [How man's efforts to feed himself have changed the face of the earth.]

Lamb, Ruth de Forest. *American Chamber of Horrors: the Truth about Food and Drugs.* Farrar & Rinehart, 1936. [Some useful information about food and drugs as biological problems, and especially as problems created by the social nature of the human species.]

Peattie, Donald Culross. *The Flowering Earth.* Putnam, 1939. [A fascinating account of chlorophyl in making the world a charming possibility for life.]

Taylor, Clara Mae. *Food Values in Shares and Weights.* Macmillan, 1942. [A useful combination of the latest scientific information about nutrition, with a practical scheme for working out dietaries.]

Food and Life. United States Department of Agriculture Yearbook for 1939.

UNIT THREE · HOW DO LIVING THINGS KEEP ALIVE?

Cannon, Walter B. *The Wisdom of the Body.* Norton, 1940. [How the parts of the body influence one another in maintaining a united front in relation to the changes of the surrounding world.]

de Kruif, Paul. *The Fight for Life.* Harcourt, 1938. [A very lively account of men's efforts to find remedies for their bodily ills.]

Gerard, Ralph W. *The Body Functions.* Wiley, 1941. [Very readable and informative on what the title promises; written for grownups but quite usable by younger people.]

Needham, James G. *About Ourselves.* Cattell Press, 1941. [The kind of being man is, both as an organism and as a social and emotional and intelligent being.]

Silverman, Milton. *Magic in a Bottle.* Macmillan, 1941. [About the medicines people use, what we know about them, and also some of the things we do not know.]

Williams, Jesse Feiring, and Oberteuffer, Delbert. *Health in the World of Work.* McGraw-Hill, 1942. [All except a very few of us work or expect to; this book tells us about how our health affects our work and also about how our work affects our health —and what we can do about it.]

UNIT FOUR · HOW DO THE PARTS OF AN ORGANISM WORK TOGETHER?

Allee, W. C. *The Social Life of Animals.* Norton, 1938. [How the individuals of various species behave in relation to one another.]

Edman, Irwin. *Arts and the Man.* Norton, 1939. [The connection between our senses, our enjoyments, and our creations.]

Gregory, Jennie. *The ABC of the Endocrines.* Williams & Wilkins, 1935. [A picture-book introduction to the glands of internal secretion.]

Menninger, Karl A. *The Human Mind.* Knopf, 1937. [A very absorbing introduction to the nature and workings of our minds and our emotions.]

Sure, B. *The Little Things in Life.* Appleton-Century, 1937. [Hormones, vitamins, enzymes, etc., and how they influence metabolism and behavior.]

Teale, Edwin Way. *Grassroot Jungles.* Dodd, Mead, 1937. [Insect life and special adaptations; beautiful illustrations.]

UNIT FIVE · HOW DO LIVING THINGS ORIGINATE?

Gerard, Ralph W. *Unresting Cells.* Harper, 1940. [Includes technical material on the living that goes on in cells, but reads easily and draws you on.]

Keliher, Alice V. *Life and Growth.* Appleton-Century, 1941. [Answers clearly the most common questions about the beginnings, development and adjustments of the individual human being.]

Knott, James E. *Vegetable Gardening.* Lea, 1941. [A practical guide to the running of a garden, applying important principles regarding the development and reproduction of plants.]

Levine, Milton I., and Seligman, Jean H. *The Wonder of Life.* Simon and Schuster, 1941. [A simple introduction to the facts of reproduction and early development.]

Quinn, Vernon. *Seeds—Their Place in Life and Legend.* Stokes, 1936. [Interesting information on the practical aspects of plant seeds in human affairs.]

Strain, Frances Bruce. *Being Born.* Appleton-Century, 1937. [An elementary account of reproduction and development.]

UNIT SIX · HOW DID LIFE BEGIN?

Benedict, Ruth, and Weltfish, Gene. *The Races of Mankind.* Public Affairs Pamphlets, 1943. [A simple and rapid survey of the problem of races, especially of races living together.]

Klineberg, Otto. *Race Differences.* Harper, 1935. [Interesting results of experimental comparisons of races, without prejudice; helps us to clear up what is and what is not important.]

Lucas, F. A. *Animals of the Past* and *The Hall of Dinosaurs.* American Museum of Natural History. [Two interesting and well-illustrated museum manuals, containing a great deal of interesting information on both the facts and the interpretation of life forms of the past.]

Scheinfeld, Amram. *You and Heredity.* Stokes, 1938. [An amusingly written and illustrated account of heredity among human beings, full of varied and reliable information; a special section on the inheritance of musical talent.]

Whitney, David D. *Family Treasures.* Cattell Press, 1942. [Fully illustrated records of the inheritance of various physical features of human beings.]

United States Department of Agriculture Yearbooks: 1936, *Better Plants and Animals, I*; 1937, *Better Plants and Animals, II.* Government Printing Office. [Splendid reference books on both the practical and the theoretical aspects of improving domesticated breeds of plants and animals.]

UNIT SEVEN · WHY CANNOT PLANTS AND ANIMALS LIVE FOREVER?

Colcord, Joanna C. *Your Community, Its Provisions for Health, Education, Safety and Welfare.* Russell Sage Foundation, 1941. [A good outline to suggest what to look for in deciding upon the practical steps citizens have to take to further the life and welfare of the community.]

Eberson, Frederick. *The Microbe's Challenge.* Cattell Press, 1941. [Makes clear everybody's concern with the interrelations between the various microbes and the human race.]

Fitzpatrick, Frederick L. *The Control of Organisms.* Bureau of Publications, Teachers College, Columbia University, 1940. [An interesting survey of man's methods for encouraging or suppressing various species of plants and animals that bear upon our lives.]

Root, Amos J. *The ABC and XYZ of Bee Culture.* Root, 1935. [A very good practical manual on all phases of raising bees and making them produce honey for us.]

Sears, Paul B. *Life and Environment.* Bureau of Publications, Teachers College, Columbia University, 1939. [An interesting and eye-opening account of the interactions between plant and animal communities.]

Zinsser, Hans. *Rats, Lice and History.* Little, Brown, 1935. [A delightful and entertaining book about things in general, but particularly about typhus fever and the relation of trivial animals to the course of history.]

UNIT EIGHT · WHAT ARE THE USES OF BIOLOGY?

Bell, Howard N. *Youth Tell Their Story.* American Council on Education, 1938. [Based on interviews with young people; clears up the connections between the problems each one has to face and the changing customs of the entire population.]

Butler, Ovid. *American Conservation in Picture and Story.* American Forestry Association, 1935. [Easy reading; shows how far-reaching the influences of any industry or business can be.]

de Kruif, Paul. *Health Is Wealth.* Harcourt, 1940. [Snappy account of the relation between our general welfare and the controllable factors that influence our health.]

Furnas, C. C. *The Next Hundred Years.* Reynal & Hitchcock, 1936. [A survey of what science has done to change our lives, with an attempt to look ahead to further changes in our welfare and our ways of living.]

Huxley, Julian S. *Science and Social Needs.* Harper, 1935. [Based on radio interviews with British scientists and others; easy reading and full of suggestions about the changing world.]

United States Department of Agriculture Yearbooks: 1940, *Farmers in a Changing World*; 1938, *Soils and Men.* [Excellent surveys of the relationship between man and the soil, and of the great changes brought about in our lives by the growth of science, seen especially from the point of view of the farming population but full of significance for all of us.]

INDEX

KEY: fāte, pref âce, câre, ăm, in fănt, ärm, ȧsk, so fȧ, ēve, ê vent, ĕnd, re cĕnt, ev ẽr, īce, ĭll, ōld, ô bey, ôrb, ŏdd, cŏn nect, fo͞od, fo͝ot, ūse, û nite, ûrn, ŭp, cir cŭs

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